FLEMING'S
LESSONS ON THE GLOBES.

Thomas Whittemore

Thomas Whitmore
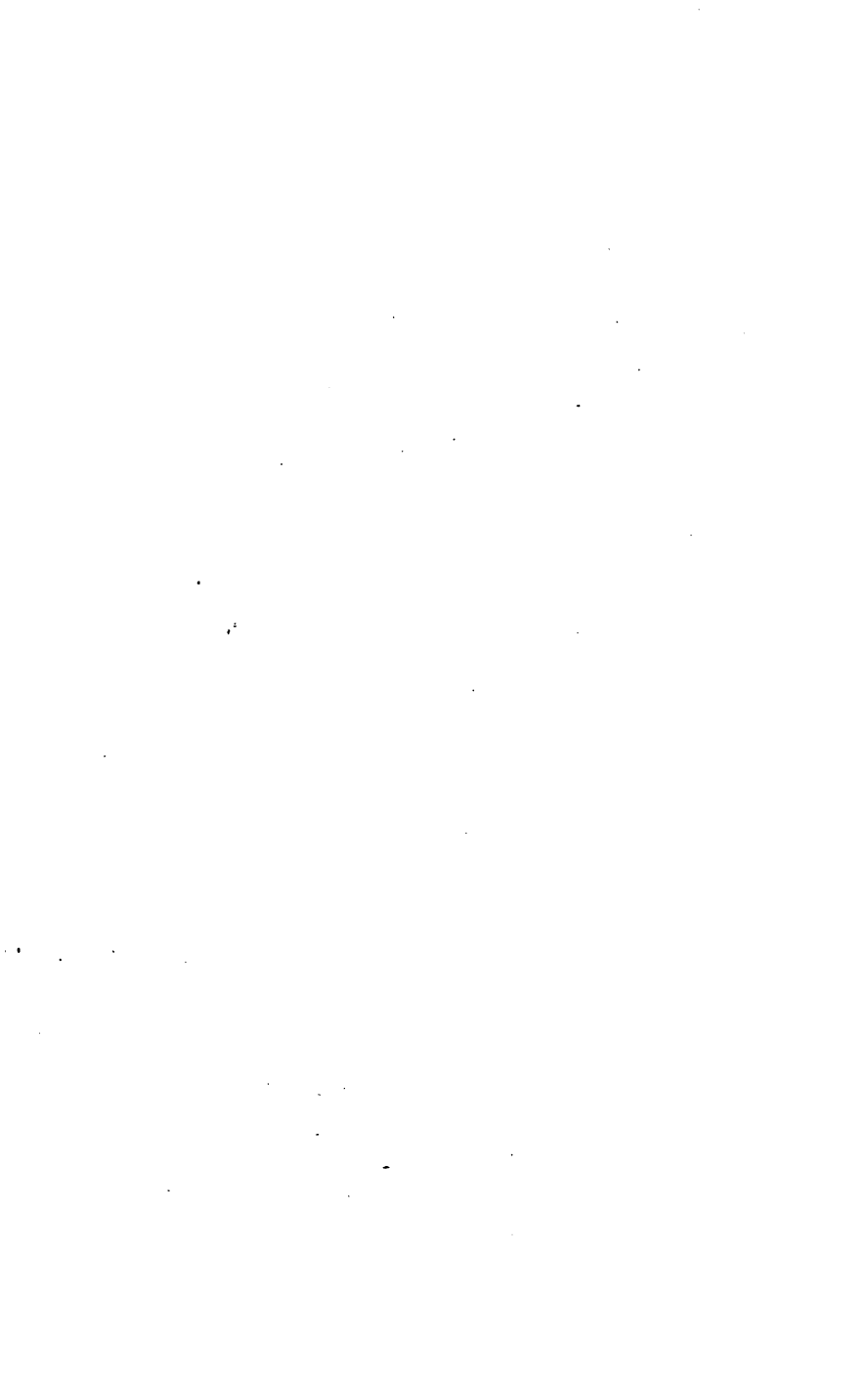
LESSONS

IN

GEOGRAPHY AND ASTRONOMY

ON

THE GLOBES.

SUPPLEMENTARY TO

THE TEXT-BOOKS GENERALLY USED ON THESE SUBJECTS.

BY

A. FLEMING.

BOSTON:
EAYRS AND FAIRBANKS.
1844.
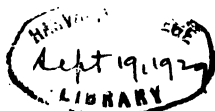
PREFACE.

THERE is no article of school apparatus which can super-sede the use of the common Globes, or which can surpass them in unquestionable utility. Maps, however useful, can-not truly represent the form of the earth or the true rela-tions of its parts. Planispheres are equally inadequate truly to represent the heavens. And Orreries usually misrepre-sent, far more than they illustrate, the motions, magnitudes, and distances of the solar system. But the Globes are min-iature *fac similes* of what they are intended to represent ; and, with all the accuracy which the artist can give to the instruments, they illustrate the phenomena and facts which they are intended to illustrate.

Pupils, whose minds have been well disciplined by the study of the pure mathematics, may possibly dispense with the use of the globes in the study of Geography and Astron-omy. But for the great majority of pupils in our common schools and academies, whose minds are not, and are not expected to be, thus thoroughly prepared and furnished, the use of the globes seems to be indispensable. And even for students in our colleges, Professor Olmsted says, " The study of artificial globes cannot be too strongly recommend-ed to the student of astronomy." Such being the case, it is surprising that these good old-fashioned implements of learn-ing are not more generally introduced into our schools than they are, and, where they are introduced, that their useful-ness is not more highly appreciated or made available.

One cause of this unmerited neglect of the globes is thought to be the want of a concise and suitable text-book to be used by the pupil along with the globes. The old treatises on the globes are too large and expensive and encumbered with extraneous matter for the present necessity; and especially are they objectionable for the empirical and dogmatical form in which they present the truths and problems which they teach. All science, properly so called, is but the development of certain fundamental ideas or principles; and no science is properly taught or understood except by a development of its first principles, — its details must be seen by the light of its fundamental ideas. This is true of Geography and Astronomy, wherein the principles and doctrines of pure geometry constitute the light by which alone a scientific knowledge of these branches of learning can be obtained.

. These same special objections to the old treatises on the globes lie with equal or greater force against abridgments of them and compilations from them ; and they furnish a sufficient reason, why the attempts of this sort which have been made have not been acceptable in our schools.

. Accordingly, the small volume herewith presented to the schools of our land is an original work. In its plan and preparation, the aim has been to direct attention to actual phenomena as seen on the earth or in the heavens, to illustrate these by means of the artificial globes, and, throughout the whole, to show the principles on which the science and its problems are founded.

The present volume does not profess to be a complete text-book in Geography and Astronomy, but only supplementary to the text-books generally used in our schools on these subjects, — supplying their deficiencies in relation to the use of the globes.

The system of questions on the text will be found very different from those usually found in our school-books.

These questions are often so contrived that the answer is a mere echo to the question, and generally they seem to be intended merely to assist the pupil in preparing for recitation, whether he understands his lesson or not, or to assist the teacher to hear recitations with but little effort or expense of time. Such questions may be serviceable to a teacher who lacks time or capacity to put extemporaneous questions, suited to the circumstances of the pupil's mind, or his difficulties at the moment. But for the good of the pupil and for a thorough knowledge of the subject, such questions are believed by many judicious teachers to be worse than useless.

The questions on the paragraphs of the text in this volume are not questions to be answered by reciting the text given. They are intended to lead the pupil's mind to some explanation of what is said, or to show whether he understands it, or to deduce some inferences from it; and they are to be answered (with the teacher's aid, if need be) from the reflections of the pupil's own mind on what is stated in the text, or on what he has already learned here or elsewhere. If any should think that such a system of questions makes the book a hard one for recitation, both to teacher and pupil, the fitting answer is, that this makes it a good one for study, for educating the thinking powers, and for producing a thorough scholarship in those who mean to be men in mind and knowledge.

It is respectfully suggested to teachers that the pupils be required to write out the replies to these questions, and that, not in the form of question and answer, but in the form of a continuous and connected narrative, statement, or process of reasoning. The same method may be pursued with the examples on the problems.

No detailed description of the globes will be found in this volume; because, it is believed, these can be learned better

1*

in the course of study, from inspection of the globes, than from any verbal description which can be given.

Some preliminary geometrical truths are prefixed to the lessons. These constitute a mere outline, with no pretension to mathematical nicety or coherence, and are intended simply to show the pupil what knowledge is preliminary to a scientific knowledge of Geography and Astronomy, and to serve for review or reference in regard to necessary preliminary truths. Every intelligent person will see that the better such truths are understood, the more rapid and sure will be the pupil's progress in the lessons. It may be here stated that a good knowledge of common arithmetic is presupposed in the student of this volume.

In some other particulars it is hoped that improvements have been introduced into this work, — which are left to speak for themselves.

Had the design of this work not been limited as it is, it might, perhaps, have assumed a more imposing form and size. But the probability of its usefulness, in the existing state of things in our schools, has been consulted in this matter. If the present attempt should be successful in restoring the use of the globes to the place it is worthy of in our schools, then, perhaps, the way will be prepared for introducing some text-book. complete in itself, on these branches of learning.

A complete set of school apparatus for the study of Geography and Astronomy should comprise the following articles, which every well furnished academy or high school ought to possess.

1. The common artificial globes, of at least twelve inches' diameter.

2. A skeleton celestial sphere, — something like the old armillary sphere, for the purpose of aiding to obtain a clear conception of the celestial globe and its various lines and circles.

3. A Theodolite, or some such instrument having motion in altitude and azimuth, for the purpose of studying the apparent motions and positions of the heavenly bodies in the heavens themselves.

4. A Telescope, the higher the power the better, for the purpose of exhibiting celestial phenomena to the pupil's eye which otherwise are hid from him.

These, with a good chronometer or common watch, would sufficiently furnish a *School Observatory* for the study of the heavens by the pupils of our schools and academies.

If, however, the present effort shall be of any service in advancing and improving the study of these important and ennobling sciences in our schools, and the youth of our country thereby become more and better acquainted with the wonderful works and ways of God on the earth and in the heavens, the highest gratification sought from his labors will be attained by

THE AUTHOR.

CONTENTS.

LESSONS ON THE CELESTIAL GLOBE.

PRELIMINARY GEOMETRICAL TRUTHS.

1. A *Circle* is a plane figure, whose outline, through-out its whole extent, is equally distant from a point within, called the centre.

The circle may be conceived as generated by the revolution of a straight line in a plane, round one of its extreme points as the centre. The other extreme point describes the circumference of the circle.

The *Radius* of a circle is any straight line drawn from its centre, to its circumference or outline.

The *Diameter* of a circle is a straight line drawn through its centre, to the circumference from side to side.

The circumference of a circle is 3·1416 times (near-ly) greater than its diameter.

The diameters and radii of circles are measured, like other straight lines, in feet, miles, &c. The circumference is measured by degrees, of which there are 360 in every circle. Each degree = 60 minutes, and each minute = 60 seconds.

Draw the figure of a circle and point out its diame-ters, radii, and circumference. — Are all the diameters,

or radii, of the same circle equal to each other or un-
equal ? — Is a degree of circular measure a fixed amount
of length, like an inch, foot, or mile ? — What length of
the circumference, in seconds, is equal to the radius ? —
In what proportion are the circumferences of different
circles to each other ? — In what proportion are the
surfaces of circles to each other ? — How, arithmetical-
ly, do you find the superficial contents of a circle ?

2. A plane angle is measured by means of an arc of
a circle described from the angular point as the centre,
the lines which include the angle thus becoming radii of
the circle.

The arc intercepted by these radii is the measure
of the angle in degrees, minutes, and seconds.

The *Complement* of an angle, or of the arc which
measures it, is what is wanting to complete 90°.

The *Supplement* of an angle, or its measuring arc, is
what is wanting to fill up the amount of 180°.

The following trigonometical lines are also used to
measure and designate angles and arcs, namely :

(1.) The *Chord* of an angle, or of its measuring
arc, — which is a straight line drawn from one extrem-
ity of the arc to the other.

(2.) The *Sine* of an angle, or its arc, — which is a
perpendicular from one extremity of the arc let fall up-
on the radius which is drawn to the other extremity of
the arc.

(3.) The *Tangent* of an angle, or its arc, — which
is a perpendicular raised from one extremity of the arc,
till it meets the radius produced, which passes through
the other extremity of the arc.

(4.) The *Secant* of an angle, or its arc, — which is

the produced radius that intercepts and determines the tangent of the same arc.

(5.) The *Co-sine*, *Co-tangent*, and *Co-secant* of an angle, are simply the sine, tangent, and secant of the complement of that angle. The co-sine of an angle is equal to that part of the radius which is intercepted between the centre and the sine.

An arc, or angle, and its supplement, have the same lines for sine, tangent, secant, etc.

The lengths of these various lines have been accurately computed — the radius being taken for unity — for all angles requisite in practice ; and the results, put in tabular forms, constitute the Trigonometrical Tables. Logarithms are generally used, instead of the natural numbers, in these tables, and in computing by means of them.

Draw a diagram of an angle and its measuring arc, sine, tangent, secant, etc. — Point out and define them. — What angle has its chord equal to radius ? — What angle has its sine equal to radius ? — What angle has its tangent equal to radius ? — What angle has its sine equal to half the chord of any given angle ? — Make the hypotenuse of a right angled triangle radius, and what parts of the triangle become the sine and co-sine of the angle at the centre ? — Make either of the sides containing the right angle radius, and what do the hypotenuse and the other side become ?

———

3. The radius, tangent, and secant of any angle together form a right angled triangle, which, for any given radius, can very easily be calculated by means of the Trigonometrical Tables. So the sine, co-sine, and ra-

2

dius form a similar triangle. It is by such calculation
that the magnitude of the earth and the distances of the
heavenly bodies are computed.

But the triangle formed by the radius, tangent, and
secant may be computed also by means of the principle,
demonstrated in Euclid, 47 prop. B. I., that the square
of the hypotenuse is equal to the sum of the squares of
the two sides.

Thus, algebraically and arithmetically, putting s for
secant, r for radius, and t for tangent, and p for the part
of s produced beyond the circle, so that

$$s = r + p$$

Then $$(r + p)^2 = r^2 + t^2$$

Whence $$2\ r = \frac{t^2}{p} - p. \ \ . \ . \ . \ . \ . \ \text{A.}$$

That is, to find twice the radius, or the diameter,
of the circle, divide the square of the tangent by the
part produced, and from the quotient subtract the part
produced ; the remainder is the diameter.

Again $$(r + p)^2 = r^2 + t^2$$

Whence $$t = \sqrt{2\ r\ p + p^2}. \ \ . \ . \ . \ . \ \text{B.}$$

That is, to find the tangent, multiply the diameter by
the part produced, to the product add the square of
this part, and the square root of the sum will give the
tangent.

Again $$(r + p)^2 = r^2 + t^2$$

Whence $$p = \sqrt{r^2 + t^2} - r. \ \ . \ . \ . \ . \ \text{C.}$$

That is, to find the part produced, add the square of
radius to the square of the tangent, extract the square
root of the sum, and from the root subtract the radius ;
the remainder is the length of the part produced.

4. A *Sphere* is a solid figure, whose circumscribing

surface, throughout its whole extent, is equally distant from a point within, called the centre.

The sphere may be conceived as generated by the revolution of a circle round one of its diameters as the axis of revolution.

Are the radii of the same sphere equal or unequal to each other ? — In proportion to what are the surfaces of spheres ? — In proportion to what are their solid contents ? — How, by arithmetic, is the extent of the spherical surface calculated ? — How are the cubic contents calculated ?

5. *Great circles* of the sphere are those made by a plane passing through the centre of the sphere.

Small circles of the sphere are those made by planes which do not pass through the centre, but through any point between the centre and the surface.

Does a great circle intersect the sphere into equal or unequal parts ? — Hemisphere ? — Does a small circle divide the sphere into equal or unequal parts ? — How do the diameters and radii of great circles and of small circles compare with those of the sphere ? — Where in the sphere is the centre of every great circle ? — Are the degrees of great and small circles on the same sphere equal or unequal to each other ? — Point out great and small circles on the Globes.

6. The *Axis* of any circle is that diameter of the sphere which passes through its centre, at right angles to its plane.

.The *Poles* of a great circle are the extreme points of
its axis. ´

Through what point in the sphere does the axis of
every circle pass ?— If a great and a small circle have
their planes parallel to each other, have they the same
axis,. or different axes ?— Can two great circles have
the same axis ?— What measures the inclination of any
two great circles to each other ?

———

7. *Secondaries* to any great circle, which is called
the *Primary*, are those great circles which intersect the
primary at right angles.

In what line do the planes of all secondaries to any
given primary intersect each other ?— In what points do
the circumferences of the secondaries intersect each
other ?— In what plane do the axes of all the seconda-
ries lie ?— In what circumference are the poles of all
the secondaries found ?

———

8. *a.* The distance between any two points on the
sphere is measured by the arc (intercepted between
them) of a great circle.

b. The distance from any point to a circle on the
sphere is measured on a secondary to that circle.

c. The position of any point on the sphere is deter-
mined by two distances ; the one, its distance from a
given primary, as measured on the secondary passing
through it ; the other, the distance of that secondary
from a given point in the circumference of the primary.

Is there but one distance between any two points on

the sphere ? — How far from any great circle to its poles ? — What do the distance of any point from a great circle, and its distance from the nearest pole of that circle, amount to ? — If two great circles intersect each other on the sphere, how far from the points of intersection to the poles of both circles ? — If a secondary to either passes through the poles of the other, will that be a secondary to both ? — In what points will the poles of this common secondary lie ? — What two arcs on this secondary are the measure of the inclination of the primaries to each other ? — Illustrate these truths on the Globes.

_____

9. Every small circle is parallel to one great circle ; and its distance from it is measured by the arc, intercepted between them, of a secondary to that parallel great circle.

And the circumference of every small circle is to the circumference of a great circle of the same sphere, as the co-sine of the distance from the small circle to its parallel great one is to radius.

Why is there but one great circle parallel to any given small circle ? — Have these the same, or different axes ? — In which two of these circles (the secondary and the small circle, or the secondary and the parallel great circle) is this co-sine found ? — In what proportion are the radius of the small circle and the radius of the parallel great circle to each other ? — In what proportion are their circumferences ?

_____

10. A spherical angle is made on the sphere, by arcs of two great circles meeting in a point. Its amount is

the inclination of the planes of the circles to each other, and is measured by the arc intercepted between the sides on a secondary to both.

A spherical triangle is formed by three arcs of three great circles, enclosing a space on the sphere.

Spherical triangles can be calculated only by the processes of Spherical Trigonometry, the knowledge of which, as well as of Plane Trigonometry, is essential to a thorough knowledge of Globular Geography and Astronomy.

LESSONS

ON THE

TERRESTRIAL GLOBE.

1. THE form of the earth on which we live is nearly
that of a sphere ; its true form being that of a spheroid,
whose polar diameter is only $\frac{1}{335}$ shorter than the equato-
rial diameter.   The mean diameter of the earth is about
7912·4 miles.

That the form of the earth is spherical, or nearly so,
is ascertained, among other ways, from this fact, that
the higher a spectator is elevated above the general sur-
face of the earth, the wider is his prospect on its surface,
and the boundary of his prospect is everywhere found to
be a circle.   This can be a fact only on the surface of
a sphere.

The magnitude of the earth may also be calculated,
with some degree of accuracy, from the known height
of the spectator and the distance on the face of the
earth to which he can see. (Preliminary Truths, 3. A.)

The *Terrestrial Globe*, therefore, is nearly an exact
representation of the form of the earth, having also the
continents, islands, seas, oceans, and other geographical
divisions of the earth, delineated on its surface in their
true forms, proportions, and situations.

How many times is the earth larger than a twelve-inch

globe ? — How much should the polar diameter of a twelve-inch globe be less than its equatorial, to represent exactly the form of the earth ? — How much should be added on the surface of a twelve-inch globe, to represent exactly a mountain on the earth five miles high ? — A spectator, on a mountain one mile high, can see on the ocean to the distance of eighty-nine miles, — what is the magnitude of the earth ? — Do maps of the world accurately represent the forms, proportions, and positions of the several parts of the earth's surface ?

2. The earth revolves on its axis once in a day, from the west towards the east, with a perfectly uniform motion. This is known from a variety of considerations, which the advanced student of astronomy alone can duly estimate.

This motion of the earth causes an apparent motion of the heavenly bodies in an opposite direction.

A similar rotation of the terrestrial globe on its axis is an exact representation of the diurnal motion of the earth.

What parts of the earth move fastest around its axis ? — How many miles in a second do the inhabitants of these parts move ? — In what proportion do other parts of the earth move slower ?   (Prelim. 9.)

3. For the purpose of determining the situation of places on the earth, two great circles are assumed, from which the distance of any place is measured, and its position thereby determined.   (Prelim. 8.)

(1.) The *Equator*, a great circle of the sphere, whose axis and poles are those of the earth's rotation.

The *Latitude* of a place is its distance northward or southward from the equator.   (Prelim. 8. *b*.)

Parallels of Latitude are small circles parallel with the equator.

(2.) The *First Meridian*, a great circle at right angles to the equator, passing through the Observatory at Greenwich near London.   Other meridians have been chosen as the First Meridian by various nations.

All *Meridians* are great circles, secondaries to the equator, consequently intersecting it at right angles and intersecting each other in its poles.

The *Longitude* of a place is the distance of its meridian eastward or westward from the first meridian.

These circles and measurements, which are conceived to be drawn on the earth's surface, are drawn on the face of the globe and its appendages.

The graduated edge of the circle, within which the globe turns, represents the meridian of any place on the globe when brought under it.   It is usually called the *Brazen Meridian*, but more significantly the *Universal Meridian* of the globe.

Why does the circle called the Equator receive that name ?—What countries are in the northern and what in the southern hemisphere ?—How many degrees of latitude can there be ?—What is the difference of latitude between 10° and 15° north ? between 20° and 45° south ? between 12° south and 4° north ?—How many parallels of latitude are drawn on the globe ?—How many may be conceived ?—What latitude have all places through which the same parallel passes ?

Why do the circles called Meridians receive that name ?—How many meridians are drawn, and how

many may be conceived, on the globe ? — How many degrees of longitude may there be ? — What is the difference of longitude between 20° east and 30° east ? between 15° east and 10° west ? between 160° west and 170° east ? — What longitude have all places on the same meridian, from pole to pole ? — What is the difference of longitude between two places on the same meridian, but each in the opposite point of it from the other ? — Are degrees of longitude of equal length in every parallel of latitude ? — Where are they greatest ? — In what proportion do they decrease in higher latitudes ?   (Prelim. 9.) — Point out and explain latitude and longitude as marked on the globe.

PROBLEM 1.

To find the latitude and longitude of any place represented on the globe.

Bring the place to the meridian of the globe ; then its latitude is seen on the meridian over it, and its longitude on the equator under the meridian.

Examples.   Find by the globe the latitude and longitude of Cape Horn, Cape of Good Hope, Cape Farewell, — the cities of London, Paris, Washington, Boston, New York, the place of your residence, and other places.

What countries are intersected by 0° latitude, — by the parallel of 10° N., — 20° N., — 30° N., &c., — by the parallel of 10° S., — 20° S., — 30° S., &c. ?

What countries, seas, or oceans are intersected by the meridian of London, — of Rome, — of Constantinople, — of Calcutta, — of Cape Farewell, — of Boston, — of Washington, — of New Orleans, &c. ?

PROBLEM 2.

The latitude and longitude of any place being given, to find its position on the globe.

Bring the given degree of longitude to the meridian of the globe, then under the given degree of latitude you find the position of the place.

Examples. What places have the following latitudes and longitudes ?

Longitude	40° 43′ E.	Latitude	64° 31′ N.
"	29° 55′ E.	"	31° 13′ N.
"	14° 21′ W.	"	7° 56′ S.
"	151° 23′ E.	"	34° 0′ S.
"	71° 3′ W.	"	42° 23 N.
"	88° 29′ E.	"	22° 35′ N.
"	3° 12′ W.	"	55° 58′ N.
"	0° 0′	"	51° 29′ N.
"	77° 55′ W.	"	0° 13′ S.

A ship was spoken in latitude 20° N., and longitude 40° W.; find the ship's place at the time. — My friend dates his letter, At sea, latitude 10° S., longitude 145° W.; where was he then ? — It is reported that land has been discovered in latitude 67° S., and from longitude 140° E. to 170° W.; show it on the globe.

———

4. The sensible horizon, or more significantly, the *Terrestrial Horizon*, of any place, is the circular boundary of a spectator's view of the earth's surface ; as seen, for example, on the wide ocean, or on an extensive prairie or plain. Seamen call this the *offing*.

A plane conceived to pass through the spectator's eye, to which a vertical or plumb line is perpendicular, is a horizontal plane ; but is not the plane of the terres-

trial horizon, except when the spectator's eye is at the surface of the earth. A line drawn from the spectator's eye to the terrestrial horizon, or offing, declines below a horizontal plane passing through the spectator's eye ; and declines more or less according to the elevation of the eye above the surface of the earth. The amount of this declination is called *the dip of the horizon.*

The terrestrial horizon of any place on the globe would be accurately represented by a circle drawn around it, more or less wide as the spectator's elevation is more or less above the general surface of the earth.

But such a circle, on our common globes, would be too small for any useful purpose, — at least for all heights usually accessible by man.

Consequently, the circular wooden frame of the globe is taken to represent the terrestrial horizon of any place when brought over its centre. This, indeed, accurately represents the terrestrial horizon of a spectator elevated so high above the place that he could see a whole hemisphere at one view.

The horizon is divided by the meridian of the place in the *North* and *South* cardinal points. A line, at right angles with the meridian passing through the place, divides it in the *East* and *West* cardinal points. Between these four points of the horizon there are other intermediate points, as also degrees.

A line drawn from the place as a centre, towards any one of these points in the horizon, is a *rhumb* line. It must cross every meridian at the same angle, unless it be the meridian itself.

These points and divisions of the horizon are inserted on the wooden frame or horizon of the globe, commonly called the wooden horizon, but more significantly the *universal horizon* of the globe.

Furthermore, the distance of the terrestrial horizon, or offing, at any place, may be calculated,— the radius of the earth and the spectator's elevation above the earth's surface being known. (Prelim. 3. B.) Also the height requisite for obtaining any given extent of horizon may be calculated.   (Prelim. 3. C.)

Point out and explain the horizon of the globe, its divisions, &c.

If you trace an east or west rhumb line round the earth, what circle will it constitute ? — If you trace a north or south line round the earth, what circle will that form ? — If you trace any other rhumb line, say a north-east one, will you return to the place of departure ? — What sort of curve will such a rhumb line form on the earth or globe ? — If you continue to follow on by such a rhumb line, will you ever reach the north pole ? — On what rhumb line must you travel ever to reach the north or south pole ? — If you sail or travel on the equator, or any of its parallels, in what direction, *by the compass*, do you travel or sail ? — If you sail or travel, say north-west, *by the compass*, what angle will your course make with every meridian which you cross ? — In this case, do you make continual progress both northward and westward ? — Will you ever return by such a course to the place of departure, or ever reach the north pole ?

From the top of a mountain one mile high above the ocean, how far on its surface can you see ? *Ans.* 39 miles. — From the Peak of Teneriffe, about 2¼ miles high, how extensive is the prospect over the Atlantic ? *Ans.* 136 miles all around. — How far can the top of that mountain be seen from the surface of the ocean ? — How wide would the terrestrial horizon be from the top of a

3

mountain 5 miles high, situated in the midst of an ocean or plain ?   *Ans.* 199 miles. — How small a circle on a twelve-inch globe would accurately represent the terrestrial horizon in each of these cases ? — How high must a spectator be elevated above the sea at Boston, to see across the Atlantic, say 3000 miles wide ?   *Ans.* 1,009 miles. — How high to see one third the distance across ? *Ans.* 124 miles.

PROBLEM 3.

To rectify the globe for the horizon of any given place.

Elevate the nearest pole equal to the latitude of the given place, then bring the place to the meridian of the globe.

Thus the given place is brought directly over the centre of the horizon of the globe, which thus is made to represent the terrestrial horizon of the place, — for a spectator, however, elevated so high above it, that he can see a whole hemisphere at once.

Example.   Rectify the globe for the horizon of Boston, Washington, London, &c.

———

5. The direct course and nearest distance from one place to another on the earth is the arc of a great circle passing through both places.   (Prelim. 8. *a.*)

When this arc is a portion of the equator or of a meridian, then the bearing, *by the compass*, of this line of direct course and nearest distance, is either east and west, or north and south, as the case may be, *throughout its whole extent*.   But, if this line of direct course and nearest distance is not an arc of the equator or a

meridian, then its bearing, *by the compass*, is continually changing throughout its whole extent.

A straight line from one place to another, drawn through the earth, is the most direct course and the shortest distance possible between them ; what arc on the surface of the earth, between those places, comes the nearest to this straight line, — the arc of a greater or a smaller circle ? — See, on the globe, whether you would take the direct course and nearest distance from Cape Farewell to Mount Saint Elias, by following their parallel of latitude ; or from Saint Petersburg to Cape Farewell.

Does the line of direct course cross any two meridians at the same angle, unless it be a portion of the equator ? — Why ? — If all the meridians were parallel, would this be so ?

On the globe there is a great circle, borrowed from the celestial globe, called the Ecliptic. Find, by the following problem, its bearing, looking westerly, where it crosses the equator at 0° longitude, — at 45° W., — at 90° W., — at 180° E. or W., — at 90° E., — and 45° E.

PROBLEM 4.

To find the line of direct course from any given place to another, and its bearing by the compass at either place, or at any given intermediate point.

Rectify the globe for the horizon of the place from which the bearing is required, and fasten the *quadrant of altitude* (so called) over it. Then the graduated edge of the quadrant, extended over the other place, will represent the line of direct course ; and its bearing

by the compass, at the place for which the globe is rec-
tified, will be seen on the horizon of the globe where the
quadrant intersects it.

To find the bearing at the other extremity, or at any
intermediate point, rectify for the horizon of the other
extremity, or of the given intermediate point, and pro-
ceed as before.

Examples. At Boston, what is the line of direct course
to Cape Clear, Ireland, and what is its bearing at Boston?
It bears E. 35° N. — At Cape Clear, what is the direct
course by the compass to Boston ? W. 12° N. — On
what point of the compass does the ship steer, keeping
on the line of direct course, when she arrives at Cape
Clear ? E. 12° S. — How many degrees has she de-
viated from her first course by compass, by keeping on
the line of direct course à From E. 35° N. to E. 12°
S. = 47°. — When she crossed the meridian of 30°
W. longitude, on what point of her horizon was she
steering ? — On what point of the horizon will she steer,
taking her departure from Cape Clear for Boston, and
on what will she arrive at Boston ?

At New York, what is the bearing of the line of direct
course to Liberia ? — at Liberia, towards New York ?—
at Jamaica, W. I., to Gibraltar ? — Gibraltar, to Ja-
maica ? — at London, to Washington? — at Washington,
to London ? — In what direction at Boston must you
look, in order to look directly towards the Cape of Good
Hope ?—A ship sails from Norfolk, Va., for Cape Saint
Vincent, Portugal, both on the same parallel of latitude ;
on what point of the compass does she steer at her
departure, and on what at her arrival at the Cape ?

PROBLEM 5.

To find the nearest distance, on the face of the earth, between any two given places.

Extend the graduated edge of the quadrant over both places, and the degrees intercepted between them, counted on the quadrant, is the distance in degrees, which, multiplied by 60, gives the distance in geographical miles, or by $69\frac{1}{15}$ gives it in statute miles nearly.

Or, a pair of compasses, a piece of thread, or the edge of a piece of paper, may be extended over the two places, and the distance between them, marked on this, and applied to the equator, will show the distance in degrees.

Examples. What is the distance from Boston to Cape Clear? — from New York to Liberia? — between New York and Liverpool? — from Boston to New Orleans? — from Maine to Florida, the extreme points?

What is the distance from Boston to the Sandwich Islands, by Cape Horn? — what, by the Isthmus of Darien? — How much shorter is the overland journey from London to Bombay by the Isthmus of Suez and the Red Sea, than the voyage by the Cape of Good Hope? — Do ships always sail on the line of direct course and nearest distance, from the port whence they depart to that whither they are bound? — Why?

6. The sun is continually shining on the earth, enlightening one half of it, where it is Day, and leaving the other half in darkness, where it is Night. But the rotation of the earth on its axis brings all parts of its surface successively into the enlightened and unenlightened hemispheres. (Article 2.)

When the sun is directly over the terrestrial meridian

3 *

of any place, it is then *Noon* at that place, in apparent solar time.   At places westward of that meridian the hours then are *before noon,* and at places eastward of it, the hours are *after noon.*

To represent the conterminous boundary of light and darkness on the face of the earth, the horizon of the globe is made use of, and is then called the *Circle of Illumination.*   The sun is supposed to be directly over its centre.   And that half of the globe which is above it represents the enlightened hemisphere, the lower half represents the unenlightened hemisphere.

Hence, the meridian of the globe represents that meridian over which the sun shines, where it is noon.

Hours and minutes are marked on the equator, and the *Hour Circle,* with its Index, serves for the computation and exhibition of time, in performing problems.

Does the sun enlighten exactly one half of the earth ?— Do all parts of the earth enjoy equal shares of the sun's light in the course of a year ? — On which side of the meridian is the sun seen in the forenoon, and in the afternoon ? — How much sooner, or later, than at a given place, is it noon, or any other hour, at 15° longitude E. from the given place ? — 15° longitude W. from it ?— 1° longitude E. ? — 15' longitude W. ? — Explain, by the globe, the circle of illumination, the position of the sun, the meridian where it is noon, &c.—Why are there two series of 24 hours on the hour circle ? — Which series is made use of in problems on the terrestrial globe ? — With how much accuracy can time be noted by the hour circle, and by the hours marked on the equator ?

PROBLEM 6.

To rectify the globe for the local time ; that is, for solar time at any given place:

Bring the given place to the meridian of the globe, and set the index to XII. Then, as the globe revolves on its axis, the index will point to the hours in succession.

Example. Rectify the globe for the local time of Boston, Hartford, &c.

PROBLEM 7.

The hour being given at any place, to determine what hour it then is at another given place, and the difference of local time at both places.

Bring the place at which the hour is given to the meridian of the globe, and set the index to the given hour. Turn the globe till the other place comes to the meridian, and then the index will point to the hour required. The difference between these hours is the difference of local time at both places.

Or, find the difference of longitude between the given places, and convert this into time arithmetically, which gives the difference of their local time.

Examples. When it is noon at Washington, what hour is it then at New York ? — at Boston ? — at London ? — at Constantinople ? — at Charleston ? — at New Orleans? — at Astoria ? — at Hawaii, Sandwich Islands? — at Canton ? — at Calcutta ? — When it is three, P. M. at New York, what hour is it then at Cincinnati ? — at Mexico ? — at Gibraltar ? — at Rome, &c. ? — When it is the hour of midnight at Quebec, what hour is it

then at the Bermudas ?— at Edinburgh ?— at Botany Bay ?

A ship sails from New Bedford, Massachusetts, to circumnavigate the globe *easterly ;* how much sooner will it be noon on board the ship than at New Bedford, when she has made 15° easterly longitude ? — when on the meridian of the Cape of Good Hope ? — when at Canton ?— at the Sandwich Islands ? — at Cape Horn ? — at Cape Saint Roque ? — at New Bedford, home again ? — If it is Sunday on shore when she arrives there, what day is it on shipboard ? — If the ship had circumnavigated the globe westerly, what difference would this have made in the result ?

The missionaries at the Sandwich Islands sailed thither by Cape Horn, and have observed the Sabbath by the ship's reckoning from America : would their Sabbath have been on the same day as now, if they had sailed thither by the Cape of Good Hope, and Canton ?

How many hours from noon to noon on board a ship which has made 15° easterly longitude, in the mean time ? — How many, if she has made 15° westerly longitude ? — 5° E. ? — 1° W. ?

PROBLEM 8.

The hour being given at any given place, to find at what places it is then a given hour.

Bring the place at which the hour is given to the meridian of the globe, and set the index to the given hour at that place. Turn the globe till the index points to the other given hour, and then the places required will be found under the universal meridian

Examples. When it is noon at Quebec, at what

places is it then seven, A. M. ?—at what, one, P. M. ?
— at what, midnight ? — When it is nine, A. M., at
Philadelphia, what is it then now ?—where nine,
A. M. ? — when nine, P. M., &c.

How far to the eastward must you go, to see sunrise
an hour before you can see it where you now are ?—
how far westerly, to see sunset thirty minutes later
than where you now are ?— forty-five minutes later ?

How fast must you travel, and in which direction,
east or west (were it possible); to have perpetual noon
during the next twenty-four hours, from noon to-mor-
row ? — How fast, to have perpetual midnight during the
next twenty-four hours, from twelve o'clock to-night ?
— In what parts of the world must you travel fastest,
to accomplish the preceding feat ? (Article 2, and
Prelim. 9.)

7. The sun is always vertical at the enlightened pole
of the circle of illumination, or a point 90° from its
circumference on the surface of the enlightened hemis-
phere. Consequently, his rays are vertical to any place
which happens to have that position at any time.

On the 20th of March and the 22d of September,
the sun is always observed to be vertical, at noon, to all
places on the earth's equator. His position is then in
the celestial equator, which is a circle in the sky direct-
ly overhead, or vertical to the terrestrial equator.

But from the vernal equinox, March 20th, to the au-
tumnal equinox, September 22d, his position declines
towards the north as far as 23½° ; and again, from the
autumnal to the vernal equinox, his position declines as
far towards the south. Consequently, the place where
his rays are vertical at noon will have a latitude from
the equator equal to his declination on any given day.

The sun's declination for every day in the year is marked in the *Analemma*, found on the terrestrial globe.

PROBLEM 9.

To find the sun's declination on any given day, by the analemma.

Bring the point of the sun's declination on the given day, as marked on the analemma, to the universal meridian, and then, over it, is marked on the meridian the amount of declination.

Examples. What is the sun's declination on the 20th of March, 1st of May, 22d of June, 22d of September, 22d of December, &c.?

PROBLEM 10.

To find on what day, or days, of the year the sun will have a given declination.

Bring the analemma to the meridian of the globe, and observe the day, or days, marked on it directly under the given degree of declination. These are the days required.

Examples. When is the sun's declination 10° north? — 13° south, &c.?

PROBLEM 11.

To find at what places on the earth the sun's rays are vertical at noon on a given day.

Find the sun's declination on the given day, then all those places having the same kind and degree of latitude with this declination, are the places required.

Examples. To what places is the sun vertical, or nearly so, at noon, March 20th, April 10th, May 15th, June 21st, August 1st, 20th, September 22d, October 20th, December 22d ? — When it is 9, A. M., at New York, January 30th, where is it noon and the sun vertical, at that moment ?   (Prob. 8 and 11.) — Where is the sun vertical at this moment ?

PROBLEM 12.

To find on what day, or days, the sun will be vertical at noon to any given place in the torrid zone.

Find the latitude of the given place, and also on what day, or days, the sun has a declination of the same kind and degree with the latitude.   These are the days required, on which the sun is vertical at noon, at the given place.

Examples. When is the sun vertical at noon, to Havana, in Cuba ? — to Kingston, in Jamaica ? — to Liberia ? — to Calcutta, Batavia, &c. ?

What is the day and hour of the day at Boston, when the sun pours his vertical rays on Ceylon ? — on the Sandwich Islands ? — on Antigua ? — What hour is it at any place, when the sun is vertical there ? — When, at Sierra Leone, does a man, standing erect, stand on the shadow of his own head ?

––––––

8. With the ever varying declination of the sun, the circle of illumination shifts its position northward or southward on the earth, — being always 90° from the place where the sun's rays are vertical.

This causes the varying length of day and night, the phenomena of perpetual day and night for long periods in the polar regions, and the changes of the seasons.

PROBLEM 13.

To rectify the globe for the sun's place or declination, and the position of the circle of illumination, on any given day.

Elevate the pole towards which the sun declines, equally to the degree of his declination, on the given day.

Thus the horizon of the globe is made to represent the conterminous boundary of light and darkness on the earth, and the sun's position is directly over the degree of his declination on the meridian of the globe, on the given day.

Examples. Rectify the globe for the sun's place November 1st, December 10th, April 12th, &c. — Rectify the globe for 13° declination north, and for 20° south.

9°. While the sun has northern declination, he enlightens more than half of the northern hemisphere of the earth, and less than half of the southern hemisphere. Hence, in northern latitudes, the days are longer than twelve hours, but in southern latitudes they are shorter than twelve hours.

∴ While the sun has southern declination, the same result happens, but in opposite hemispheres.

PROBLEM 14.

To determine, for any given place and day, the hour of sunrise, sunset, and the length of the day and night.

Rectify the globe for the sun's declination on the given day, and also for solar time at the given place. Then bring the given place to the western verge of the enlightened hemisphere, and the index will point to the hour

of sunrise ; — bring it to the eastern verge of the same, and the index will point to the hour of sunset, apparent time at the given place.

The hour of sunrise doubled is the length of the preceding night, and the hour of sunset doubled is the length of the preceding day.

Examples. What is the hour of sunrise and of sunset at Burlington, Vermont, March 20th, May 10th, June 21st, August 1st, September 22d, &c., and what is the length of the day and of the night there, at each of these dates ?

Find the length of the day, March 20th, at St. Petersburg, — at London, — at New York, — at Quito, — at Buenos Ayres.—Find the same, September 22d, at the same places. — What is the duration of daylight, April 10th, at Boston ? — at Cape Horn ? — at Canton ? — at Moscow ? — What is the length of the longest day, June 22d, at St. Petersburg ? — at Edinburgh ? — at the Shetland Islands, and other places in the northern temperate zone ? — The longest night at the same places ? — What is the length of the longest day, December 20th, at the Cape of Good Hope ? — at Cape Horn ? — at Botany Bay, and other places in the southern temperate zone ? — What is the length of the longest night at Archangel ? — at Quebec ? — at Havana, in Cuba ? — What is the length of the shortest day and night at Stockholm ? — How much does the longest day exceed the shortest, at New Orleans ? — at Washington ? — at New York ? — at Quebec ? — at Cape Farewell ?

PROBLEM 15.

The day and hour being given at any given place, to

4

determine the circumstances of day and night for all places throughout the world.

Rectify the globe for the sun's place on the given day, and for the local time of the given place. Turn the globe till the index points to the given hour.

The globe then accurately represents the position of the earth, at the given hour and day, in relation to the sun.

All those parts of the earth which are above the circle of illumination have day, and those parts below it have night.

The sun is rising to all places at the western verge of the enlightened hemisphere, and he is setting to all places at its eastern verge.

Those places which are at the upper meridian from pole to pole have then the hour of noon, and those at the lower meridian have the hour of midnight.

It is before noon, at all places between the western verge of the enlightened hemisphere and the meridian; and it is after noon, at all places between the meridian and the eastern verge of the same.

At the place directly under the degree of the sun's declination, the sun is seen over head; at all places within the enlightened hemisphere, directly north of this, the sun is seen on the meridian in the south; and at all places within the enlightened hemisphere, directly south of the same, the sun is seen on the meridian in the north.

Examples. When it is noon at New York, April 10th, what are the circumstances of day and night at other places throughout the world ?—What are the circumstances of day and night throughout the world, at this present moment ?

———

10. When the sun has no declination, the boundary of the enlightened hemisphere extends from pole to pole. But when he has declination, the boundary of the enlightened hemisphere extends beyond the pole towards which the sun declines, and as much beyond it as is equal to his declination at the time.

In like manner, the boundary of the enlightened hemisphere falls as far short of the opposite pole.

Hence, there is a space around the enlightened pole, within which there is perpetual day, during a certain portion of every year. And at the same time, there is an equal space around the opposite pole, where it is perpetual night, during the same time.

The circles which bound these spaces, called the circles of perpetual day and night, are constantly enlarging and contracting their dimensions, with the varying declination of the sun. Their co-latitude, or polar distance, is always equal to the declination of the sun at the time.

Explain these facts by Problem 15, for March 20th and September 22d, May 10th and August 1st, October 20th and January 20th. — During what part of the year is the circle of perpetual day in northern regions enlarging ? — And when is it contracting ? — When the circle of perpetual day is enlarging around one pole, how is it with the circle of perpetual night around the other ?

PROBLEM 16.

To determine what circumpolar regions have light, and what have darkness, during the whole twenty-four hours, on any given day of the year.

Rectify the globe for the sun's declination on the giv-

en day. Then all those places around the elevated pole, which revolve entirely above the circle of illumination, have light during the whole twenty-four hours of that day; and all those places around the opposite pole, which revolve entirely beneath the circle of illumination, have night during the whole twenty-four hours of that day.

Or, find the sun's declination on the given day, and observe what places around the poles have a co-latitude equal to this and less than this, but not greater; those places around the pole, towards which the sun declines, have perpetual day; those around the opposite pole have perpetual night, during the whole twenty-four hours on the given day.

Examples. What places on the earth have twenty-four hours of daylight on June 10th, August 15th, February 1st, April 3d, March 20th, September 22d ? — What places have darkness during the same, on the same days ?

PROBLEM 17.

To determine on what day of the year the sun will begin to shine, during the whole twenty-four hours, and on what day he will cease to shine, during the whole twenty-four hours, at any given place in the polar regions; and the length of perpetual day and night at the given place.

Elevate the pole nearest the given place, till the given place in its diurnal revolutions just touches the circle of illumination. Find on what days of the year the sun has a declination towards the same pole, equal to this elevation of the pole. These are the days required for

the beginning and ending of perpetual day at the given place.

Again, find on what days of the year the sun has a declination towards the opposite pole, equal to this elevation of the pole. These are the days required for the beginning and ending of perpetual night at the given place. Then find, arithmetically, the length of perpetual day and night at the given place.

Or, simply find when the sun's declination, as above, is equal to the co-latitude of the given place. These are the days required.

Examples. On what days of the year does the sun begin and cease to give twenty-four hours of daylight at Melville Island ? — at North Cape ? — What is the duration of perpetual day at Spitzbergen ? — the duration of uninterrupted night there ? — How many days of *alternating light and darkness* intervene between the seasons of perpetual day and night, at Spitzbergen ? — How long is perpetual day and night at the poles ? — (Is there any allowance made for refraction in this problem ?) — What days of the year divide the seasons of perpetual day and night into two equal portions ?

————

11. When any place enters within the verge of the enlightened hemisphere, the sun begins to appear above the horizon of that place. And the more the place advances within the enlightened hemisphere, the higher the sun will appear to ascend above the horizon of the place.

Moreover, the sun's position being always directly over the place where his rays are vertical at any given time, the sun is seen in the same direction from the giv-

en place, which the place of vertical rays bears from
the given place, at the same time.

Thus we are enabled to ascertain, indirectly, the alti-
tude and bearing of the sun for any given place and time.

The same, however, can be ascertained directly by
the celestial globe and on other principles.

PROBLEM 18.

To ascertain the altitude and bearing of the sun, as
seen at a given place and time.

Rectify the globe for the sun's declination at the given
time, and for solar time at the given place, and turn the
globe till the index points to the given hour.

Then the quadrant of altitude, fixed at the degree of
the sun's declination, and extended over the given place,
will show the number of degrees between the given
place and the circle of illumination. The same number
of degrees is the altitude of the sun at the given time.

Or, find where the sun is vertical at the given time,
and mark the place. Then find the line of direct course
and nearest distance from the given place to the place
of vertical rays.

That distance, in degrees, is the complement of the
sun's altitude above the horizon, and that bearing is the
sun's bearing, as seen at the given place and time.
(Problems 11, 4, and 5.)

Examples. At Quito, September 22d, how high
and in what direction is the sun seen at nine, A. M., at
twelve, M., and at three, P. M. ? — At Buenos Ayres,
January 1st, three o'clock, P. M., how high and in
what direction is the sun seen ? — At Melville Island,
June 22d, twelve, P. M., how high and in what direc-

tion is the sun seen ? — also at six, P. M., same day ?
— and at six, A. M., next day ?

12. The light of day is prolonged by the morning
and evening twilight, — a phenomenon caused by the
refractive and reflexive powers of the atmosphere on
the sun's rays.

The duration of twilight, at different times and places,
is varied by the same causes which vary the length of
day and night at different times and places.

But in all cases it is found, that the morning twilight
begins, and the evening twilight ends, when the sun is
about 18° below the horizon of the place, that is, when
the place is about 18° within the verge of the *unen-
lightened* hemisphere.

PROBLEM 19.

To determine the hour when morning twilight begins,
and when evening twilight ends, for any given time and
place.

Rectify the globe for the sun's declination on the
given day, and also for solar time at the given place.
Fasten the quadrant of altitude at the degree of the
sun's declination.

Then turn the globe till the given place is 18° below
the western verge of the enlightened hemisphere, as
measured by the quadrant ; and the index will then
point to the required hour when morning twilight begins.

Evening twilight ends as long after sunset, as morning
twilight begins before sunrise. The hour for the begin-
ning of the one, and the hour for the ending of the
other, are equally distant from midnight.

Or, the hour for the ending of evening twilight may

be found by bringing the given place to the eastern verge of the enlightened hemisphere, and proceeding as above.

Examples. When does twilight begin and end at Boston, June 22d ? — December 20th ? — March 20th ? — September 22d ? — What is the duration of twilight at Quito, — at New Orleans, — at New York, — and at Quebec, August 15th ?

PROBLEM 20.

To determine what circumpolar regions have, or have not, twilight, at any given time.

Rectify the globe for the sun's declination on the given day, and fasten the quadrant of altitude at the degree of the sun's declination.

Then, as the globe revolves, observe what places, if any, around the depressed pole where it is perpetual night, do not come at all within 18° of the circle of illumination. These places have no twilight at all.

Observe what places do come within 18° of the same circle, during part of their diurnal revolution. These places have *some twilight;* and the duration of it, for any one place, may be measured by observing (by means of the hour circle adjusted to the local time) when it begins and ends.

And those places, if any, which perform their entire revolution within 18° of the same circle, have twilight during the whole twenty-four hours of the given day.

Observe, also, what places around the elevated pole do not sink more than 18° below the circle of illumination, while they revolve under it. These places have twilight at midnight, on the given day, and consequently during the whole night.

Examples. How far from the north pole is there no twilight at all, December 20th ? — Between what limits is there some twilight on the same day ? — Where is there twilight during the whole night on that day ? — What circumpolar regions have twilight, January 1st ?

What places have twilight during the whole night, June 22d ? — What is the lowest latitude north, where there is twilight at midnight, May 10th ? — When the sun's declination is 9° south, describe the circumstances of twilight in the northern hemisphere.

---

13. The change of the seasons, Summer and Winter, is owing to the variation in the length of day and night, and to the greater or less obliquity with which the sun's rays fall on the earth at any given place. Both these causes are produced by the varying declination of the sun. Other causes, however, protract the times of greatest heat and cold beyond the mid-days of summer and of winter respectively.

Those inhabitants of the earth, who have simultaneously the same season, but day and night alternately, are called the Periœci of each other.

Those inhabitants of the earth, who have the same season alternately, but day or night simultaneously with each other, are called the Antœci of each other.

And those, who have the same season and day or night alternately with each other, are called the Antipodes of each other. They live at points diametrically opposite to each other.

PROBLEM 21.

To determine the periœci, the antœci, and the antipodes, of any given place.

Bring the given place to the meridian, and set the index to XII. The antœci are then found at the meridian, under the same degree of opposite latitude with that of the given place.

Turn the globe till the index points to the other XII. Then the periœci are found at the meridian, under the same degree of the same latitude with that of the given place. And the antipodes are found at the meridian, under the same degree of opposite latitude with that of the given place.

Or, the latitude and longitude of the periœci, the antœci, and the antipodes, may be found by calculating from the latitude and longitude of the given place ; and with these elements their positions may be found by Problem 2.

Examples. Where do the periœci, the antœci, and the antipodes of London reside ? — of Washington ? — Boston ? — Madrid, &c. ?

14. The preceding phenomena and problems, relating to the sun and the earth's relations to that luminary, belong properly to astronomy ; and by means of the celestial globe, the same phenomena may be illustrated and problems solved, but on different principles.

Besides what has been already described, there are usually drawn on terrestrial globes an ecliptic, together with a calendar, circles of azimuth and of amplitude, and a table of the equation of time is inserted on the horizon of the globe. These circles and their appendages belong exclusively to the celestial globe.

And the only conceivable use of having them drawn on the terrestrial globe is, that, when no celestial globe

is at hand, we may use the terrestial as a celestial globe in all problems relating to the sun and the relations of the earth to the sun. When so used, it should no longer be called or considered a terrestrial, but a celestial globe, with the earth reduced to a mere point at its centre.

The ecliptic, therefore, and these other matters, will be described in the subsequent part of this work.

LESSONS

CELESTIAL GLOBE.

1. To the eye of Sense the sky seems to be a vast hollow sphere, having the earth at its centre, the fixed stars on its concave surface, and the sun, moon, and planets apparently moving among them.

Modern Astronomy, however, demonstrates to the eye of Reason that no such sphere really exists ; but that the fixed stars are situated in the regions of space, at distances immeasurably great from each other and from the earth, and that the sun is a great central body, round which the planets (including the earth) revolve at various known distances, in accordance with the laws of motion and gravitation.

Nevertheless, for the purposes of descriptive and practical astronomy, such a sphere is conceived to exist, with the earth at its centre ; and its magnitude is assumed to be so immeasurably great, that the earth in comparison is but a mere point, the centre of the sphere.

The Celestial Globe is an accurate representation of the celestial sphere. It is therefore to be conceived as a hollow globe, its centre representing the earth, from which we look up to the celestial scenery depicted on its concave surface.

The pupil must clearly understand, and always bear in mind, that, while he looks on the convex surface of the globe from without, the inhabitants of the earth are to be conceived as looking up on its concave surface from the centre within.

2. The fixed stars are delineated on the surface of the celestial globe in their true apparent positions as seen in the sky, and according to their relative apparent magnitudes or degrees of brightness. They are also arranged into Constellations, according to ancient custom, for the convenience of reference. The individual stars of each constellation are designated by the letters of the Greek and Roman alphabets, and by numerals. Some of the stars have also proper names.

The Greek Alphabet.

α	Alpha,	ν	Nu,
β	Beta,	ξ	Xi,
γ	Gamma,	ο	Omicron,
δ	Delta,	π	Pi,
ε	Epsilon,	ρ	Rho,
ζ	Zeta,	σ	Sigma,
η	Eta,	τ	Tau,
θ	Theta,	υ	Upsilon,
ι	Iota,	φ	Phi,
κ	Kappa,	χ	Chi,
λ	Lambda,	ψ	Psi,
μ	Mu,	ω	Omega.

How many magnitudes are designated on the globe? — by what characters? — How many of these magnitudes can be seen in a clear sky, by the naked eye? — telescopic stars? — double stars? — variable stars? — nebulæ? — the Milky Way?

Point out, and name, the constellations on the globe. — Name the stars in the constellation Orion, — in Ursa Major, — in Leo, &c.

———

3. The celestial sphere apparently revolves round the earth from the east towards the west, once every day. The time of an entire revolution of the fixed stars constitutes a sidereal day. It is the only true standard of time which nature exhibits.

This motion of the celestial sphere is, however, merely apparent, not real ; being caused by the diurnal rotation of the earth on its axis. (Lessons on Ter. Globe, art. 2.)

Hence, the axis of the earth's rotation prolonged becomes the axis of the celestial sphere ; and its extreme points are the celestial poles.

This apparent motion of the sphere is represented by a similar motion of the celestial globe on its axis. It is this apparent motion of the heavenly bodies, which alone is employed in explaining celestial phenomena and in solving problems by means of the celestial globe.

In what direction are the celestial poles from the poles of the earth ? — Will any line on the earth's surface, if parallel to the earth's axis, point to the celestial poles without any appreciable deviation ? — Why so ? — Turn the globe in the proper direction to represent the diurnal revolution of the celestial sphere.

———

4. The celestial *Equator*, or the Equinoctial, is a great circle of the sphere, equidistant from the poles of the sphere, which are, therefore, the Equinoctial Poles. (Prelim. *b.*)

Celestial Meridians are great circles, secondaries to the equinoctial, crossing it at right angles and intersecting each other in its axis and poles. (Prelim. 7.) Two of these are called Colures.

The position of any fixed star or point on the sphere is determined by its declination and right ascension, just as the situation of places on the earth is determined by their latitude and longitude. (Prelim. 8.)

The *Declination* of a heavenly body is its distance north or south from the celestial equator.

The *Right Ascension* of a heavenly body is the distance of its meridian, as measured on the equinoctial, eastward from the vernal equinox.

Right ascension is estimated either in degrees, or in hours and minutes of sidereal time.

The equinoctial point is not an absolutely fixed point, but recedes or moves westward at the mean rate of 50.1″ a year.

Point out on the globe the Equinoctial, and the Meridians and Colures. — How many meridians are drawn on the globe ? — Why so many, and what name do they take for that reason ? — How many may be conceived ? — The universal meridian ?

How is declination reckoned, and on what circle must it be measured ? — Parallels of declination ? — How is the celestial equator situated in relation to the terrestrial equator ? — If a straight line is drawn from the centre of the earth through any parallel of latitude on the earth, and is produced to the celestial sphere, what parallel of declination will it intersect ?

Point out the degrees and hours of right ascension, as marked on the globe. — How do you convert, arithmet-

ically, degrees into hours, or hours into degrees, of right ascension ? — Does the right ascension of the fixed stars remain the same from age to age ? — If not, does it increase or decrease, and how much ? — Can any globe exhibit accurately the right ascension of the fixed stars for any length of time ? — In how many years will the deviation amount to 1° ? — Does this affect the position of the stars in relation to each other ?

PROBLEM 1.

To find the right ascension and declination of any given heavenly body.

Bring the given body to the universal meridian of the globe. Then its declination is seen marked over it on the meridian ; and its right ascension on the equinoctial at the point where the meridian intersects it.

Examples. What are the declination and right ascension of Sirius ? — of Lyra ? — Spica Virginis ? — α Leonis ? — Between what degrees of declination and right ascension does the constellation Leo lie ? — Andromeda ? — Orion ?

PROBLEM 2.

The declination and right ascension of any heavenly body being given, to find it on the globe.

Bring the given degree of right ascension to the meridian of the globe. Then under the given degree of declination is the position of the body sought.

Examples. What stars do you find having the following elements of position ?

Right ascension 67°   Declination 17° north.

Right ascension 149° 30′   Declination 13° north.
       "   199°   "   10° south.
       " 14 hours 6 min.   "   20° north.

Find the position of the moon, when her declination is 28° north, and right ascension 175°. — What is the position of Venus, her declination being 15° south, and right ascension 3 hours 30 minutes ?

PROBLEM 3.

To determine the distance between any two heavenly bodies on the sphere.

Lay the graduated edge of the quadrant over both the heavenly bodies ; and the degrees intercepted between them is the distance required.

Or, the same distance taken with a pair of compasses, or a piece of thread, and extended on the equinoctial, or any other graduated great circle, will show the distance required. . (Prelim. 8.)

Examples. What is the distance between Castor and Pollux ? — between Alioth and Regulus ? — between Lyra and Spica Virginis ?

5. The Celestial Horizon of any place on the earth is the circular boundary of our view of the sky at that place, as seen, for instance, on the ocean or an extended plain. A vertical line, as a plumb line, is perpendicular to the plane of the horizon.

To a spectator's eye at, or very near, the level of the ocean or plain, the horizon divides the sphere into two hemispheres, the upper or visible, and the lower or invisible hemispheres.

The plane of such a horizon, however rationally con-

5 *

sidered, passes through the centre of the earth. Hence it is called the Rational Horizon. But, as the whole earth is but a point, compared with the magnitude of the celestial sphere, any horizon, whose plane is at right angles to a vertical line, will divide the sphere into two hemispheres ; and to a spectator's eye situated in this plane, at the level of the ocean, precisely one hemisphere is visible.

When the spectator is elevated above the surrounding level surface of the earth, owing to the convexity of that surface, he sees more than a hemisphere above his horizon. The excess is called the Dip of the Horizon.

A vertical line, at any place, is the axis of the horizon, when produced both ways to the surface of the sphere. Its upper pole is called the Zenith of the place. The opposite pole is called Nadir.

Do the inhabitants of any given place, and their antipodes, see the same celestial hemisphere at the same time ? — The dip of the horizon, as seen from the Peak of Teneriffe, is 2° ; what portion of the sky is at once seen by a spectator on the Peak and by the antipodes at the level of the ocean ? — If the antipodes is elevated as high as the Peak above the level around, how much of the sphere do both parties see in common ?

How many degrees from the zenith to the rational horizon of any place ? — from nadir to the horizon ? — from zenith to nadir ?

Point out on the globe the universal horizon, its zenith and nadir. — Where in the globe is the spectator's situation, who has the universal horizon for his horizon, and what direction is up, to him ? — What direction is

down ? — What direction is neither up nor down to him ?

———

6. The celestial equator being in the same plane with the earth's equator, it follows that the zenith of every place on the earth has a declination equal to the latitude of the place, and of the same name.

Likewise, the celestial pole, having the same name with the latitude of the place, is elevated above the horizon equally to the latitude of the place, or the declination of its zenith.

What celestial circle passes through the zeniths of all places at the earth's equator ? — What point coincides with the zenith at the earth's poles ? — What is the declination of the zenith at the parallel of 30° north latitude ? — 45° south latitude, &c. ?

If the equinoctial passes through the zenith, in what circle do you find the celestial poles ? — Why so ? — As the zenith declines northward, or southward, which pole becomes elevated above the horizon, and how many degrees ? — How much is the opposite celestial pole depressed below the horizon of the place at the same time ?

By means of an astronomical quadrant, I observe the zenith distance of a star on the equinoctial to be 35° ; what is the latitude of the place ? — On the wide ocean, I find the north pole to be 52° above my horizon ; in what parallel of latitude am I ? — The zenith distance of the north pole is observed to be 38° ; what is the latitude ? — The sun, then in the celestial equator and on the meridian of the place of observation, is 52° above the horizon in the south ; what is the latitude ? — 52° in

the north; what is the latitude? — 10° in the north; what
is the latitude? — The sun on the meridian is 56° above
the horizon in the south, his declination being 4° north;
what is the latitude? — 48° elevation, and 4° declination
south; what is the latitude of the place of observation?

By what means do navigators and travellers ascertain
the latitude of the place where they are at any time?

PROBLEM 4.

To rectify the globe for the celestial horizon of any
given place.

Elevate the pole, having the same name with the lati-
tude of the place, equally to the latitude of the place.

Thus the universal horizon of the globe becomes the
horizon of the place, its zenith is at the degree of decli-
nation which is equal to the latitude of the given place,
and the pole is elevated above the horizon equally to the
same.

Examples. Rectify the globe for the horizon of New
York, Boston, Quito, 10° south latitude, 45° north lati-
tude, 90° north latitude, and 90° south latitude; and
point out the zenith and nadir, the visible and the invisi-
ble hemispheres, in each case.

———

7. Circles, which are secondaries to the rational hori-
zon, are called Vertical Circles, their planes are vertical
to the horizon.   (Prelim. 7.)

That vertical, which passes through the north and
south points of the horizon of any place, is the Celestial
Meridian of that place, or the meridian which passes
through the zenith of the place.

That vertical which passes through the east and west

points of the horizon of any place is called the Prime Vertical.

The position of any heavenly body in the visible hemisphere is determined by its altitude and its azimuth or amplitude.

The Altitude of a heavenly body is its elevation above the horizon, as measured on the vertical circle passing through it. If the vertical be the meridian, then the altitude is called the meridian altitude. This being the highest altitude which a heavenly body can attain in its diurnal revolution, it is then at its *culminating point.*

The Azimuth of a heavenly body is the distance, measured on the horizon, to its vertical from the north or south points of the horizon.

The Amplitude of a heavenly body is the distance, measured on the horizon, to its vertical from the east or west points of the horizon.

The degrees of amplitude and azimuth are marked on the horizon of the globe, and the quadrant of altitude, when fastened at the zenith, represents a portion of a vertical circle and serves for measuring altitude.

In what axis do the planes of all verticals intersect each other? — Through what points do all verticals pass? — To what plane are the planes of all verticals perpendicular? — How many degrees of azimuth and amplitude can there be? — How many degrees of altitude and of zenith distance can there be? — Which of these are complements of each other? — Where is a heavenly body, when it has neither azimuth nor amplitude?

PROBLEM 5.

To determine the bearing, azimuth, or amplitude, and the altitude of a heavenly body, for any given place.

Rectify the globe for the horizon of the place, and fasten the quadrant of altitude at the zenith. Lay the graduated edge of the quadrant over the given heavenly body.

Then where the quadrant intersects the horizon is the point of bearing, azimuth, or amplitude.

The distance intercepted on the quadrant between the horizon and the given body is its altitude.

Examples. What is the meridian altitude of the star Aldebaran at Boston ? — While that star is on the meridian of the same place, what are the bearing, azimuth, amplitude, and altitude, of the following stars, — Regulus, Sirius, Procyon, Alioth in Ursa Major, Alpherita in Andromeda, and other stars then visible ? — Find the same for the latitude of Charleston. — What is the greatest and the least altitude of the star Alioth, when on the meridian of Boston ? — How is the latitude deduced from these altitudes ?

8. The sun's place among the fixed stars is not always the same, but he is observed to have an apparent motion eastward round the sphere. This, however, is caused by the motion of the earth round the sun.

From daily observations on the sun's declination and right ascension throughout the year, it is known, that the sun's apparent path among the constellations is a great circle of the sphere, in which he performs an entire revolution once in a year.

This circle, called the Ecliptic, crosses the equinoc-

tial in two opposite points, called the Vernal and Autumnal Equinoxes, or Equinoctial Points ; and it forms an angle with the equinoctial, which is measured by the sun's greatest declination, nearly 23½° (23° 27′ 54″). This angle is variable within narrow limits.

The equinoctial points are observed to have a slow motion westward, at the rate of 50.1″ in a year. This is called the Precession of the Equinoxes.

Intermediate between the equinoxes, and equally distant from them, are the Solstices, or Solstitial Points, where the sun's declination is at the maximum.

On the globe the ecliptic is drawn, divided into twelve signs of 30° each, reckoning from the vernal equinox eastward. And on the larger globes the sun's place is marked for every day in the year on the ecliptic, as well as in the calendar.

Have you ever observed the progress of the sun eastward among the stars ? — How do observations on the declination and right ascension enable you to ascertain that the sun's apparent path is a great circle ? — About how much does the sun advance in a day in the ecliptic ? — Is this motion real, or merely apparent ? — Point out the ecliptic on the globe, the equinoxes, the solstices, the winter and summer signs, the ascending and the descending signs. — Repeat the signs in order.

PROBLEM 6.

To find the sun's place in the ecliptic on any given day of the year.

Find it by inspection on the ecliptic, or in the calendar, at the given day.

Examples. At what degree of what sign is the sun, February 13th, October 23d, December 21st ? — Mark the sun's place on the ecliptic, for January 1st, May 10th, and to-day. — February 29th.

———

Note. — A small disc of gilt paper, stuck on the sun's place, by being wetted slightly, is a very neat and convenient way of marking the sun's place.

PROBLEM 7.

The sun's place being given among the signs, to find the day of the year.

Find it by inspection on the ecliptic, or in the calendar, at the given sign and degree.

Examples.   When is the sun at the vernal equinox ? — at the autumnal ? — at the winter and summer solstices ? — at 13° in Cancer ?

———

9. The ecliptic has its poles and its secondaries, analogous to those of the equinoctial.

By means of these, the position of heavenly bodies, particularly that of the sun, moon, and planets, is determined by latitude and longitude.

Celestial Latitude is the distance of a heavenly body from the ecliptic towards its north or south pole.

Celestial Longitude is the distance measured on the ecliptic eastward from the vernal equinox, to the secondary circle which passes through the heavenly body.

Hence, the secondaries to the ecliptic are called Circles of Celestial Longitude.

Point out on the globe the poles of the ecliptic and

its circles of longitude. — How many degrees of celestial latitude may there be ? — How many signs and degrees of longitude ? — In what do celestial and terrestrial latitude and longitude agree, and differ ? — How do declination and right ascension differ from celestial latitude and longitude ? — How many circles of longitude are there ? — How many parallels of latitude ? — Do the longitude and latitude of the fixed stars remain the same from age to age ? — In how many years will the increment in longitude amount to a degree ? — Can a celestial globe show accurately the latitude and longitude of the fixed stars for a long series of years ?

PROBLEM 8.

To find the latitude and longitude of a given heavenly body.

Lay the graduated edge of the quadrant over the given heavenly body and over the ecliptic pole nearest to it, *zero* on the quadrant being placed at the ecliptic.

Then the latitude sought is found marked on the quadrant over the given heavenly body.

And the longitude sought is found marked on the ecliptic, where it is intersected by the quadrant.

Examples. What are the latitude and longitude of the star Deneb in Leo ? — Mirach in Andromeda ? — Dubhe, or α, in Ursa Major ? — of the sun, on March 21st ? — May 10th ? — to-day ?

PROBLEM 9.

The latitude and longitude of a heavenly body being given, to find its position on the globe.

Lay the quadrant, at zero, over the given degree of

6

longitude, and also over the ecliptic pole towards which
the given latitude is reckoned.

Then under the given degree of latitude on the quad-
rant, you find the position sought of the heavenly body.

Examples. Find the position of the following ele-
ments : — Longitude 9 signs 12°, latitude 61½° N. —
longitude 6 signs 21°, latitude 2° S. — Find the moon's
place, her longitude being 15° in Capricorn, and lati-
tude 3° S.

PROBLEM 10.

The latitude and longitude of a heavenly body being
given, to find its declination and right ascension.

With the given elements, find its position by problem
9. Then find the declination and right ascension of
that position, by problem 1.

Example. What are the declination and right as-
cension of the examples given under problem 8 ?

PROBLEM 11.

The declination and right ascension of a heavenly
body being given, to find its latitude and longitude.

With the given elements, find its position by problem
2 ; and then find the latitude and longitude of that posi-
tion by problem 8.

Example. What are the latitude and longitude of
the examples given under problem 2 ?

Miscellaneous. What are the sun's declination and
right ascension March 21st, May 3d, August 1st, Sep-
tember 22d, October 23d, December 21st, June 21st ?

when his longitude is 8 signs 15° ? — when at 4° in Capricorn ? — When the sun's right ascension is 57½°, what are his declination, his longitude, and the day of the year ? — when his right ascension is 17 hours and 45 minutes ?

---

10. A sidereal day, at any place, is the time which elapses from the instant when any fixed star or point is on the meridian, until it is on the meridian again.

Astronomers have taken the vernal equinoctial point, as that which, when on the meridian, indicates the commencement of the sidereal day. Astronomical clocks for sidereal time are regulated accordingly, and they show, in one series of 24 hours, the right ascension of any heavenly body on the meridian at any time.

An apparent solar day, at any place, is the space of time which elapses from the instant that the sun is on the meridian, until he is on the meridian again the next day.

Astronomers and navigators at sea begin the solar day at noon, and the former reckon the hours in one series of twenty-four. The civil day is reckoned from the hour of midnight, merely for convenience in the common affairs of life.

The time indicated by the hours marked on the equinoctial and on the hour circle of the globe is strictly sidereal time ; but it is sufficiently accurate for solar time, in solving problems by the globe.

PROBLEM 12.

To rectify the globe for solar time on any given day.

Bring to the meridian the sun's place in the ecliptic on the given day, and set the index of the hour circle to XII.

Then, as the globe revolves westwardly, the index will point to the hours in succession, till the sun's place in the ecliptic on the next day comes to the meridian.

And the hours marked on the equinoctial, as they successively come to the meridian, indicate the sidereal time of the astronomical clock.

Examples. Rectify the globe for solar time August 1st, December 10th, April 3d. — What is the hour, sidereal time, at noon, on August 1st ? — What is the hour, sidereal time, December 10th, at three, P. M., solar time ? — What is the hour, solar time, May 20th, at eighteen hours thirty minutes, sidereal time ? — A star is on the meridian, at thirteen hours twenty minutes, by the sidereal clock ; what is the star's right ascension ?

———

11. An apparent solar day comprises the time of an entire diurnal revolution of the sphere, and as much more as the sun has moved eastward, or increased his right ascension, during the day.

Hence, every apparent solar day is longer than a sidereal day, by the amount of the sun's increment of right ascension made on that day.

But the daily increment of the sun's right ascension is not the same throughout the year ; hence, a day of twenty-four hours, in apparent solar time, is not of the same length throughout the year.

This inequality arises from three causes.

(1.) The sun's motion in the ecliptic is not uniform. This arises from the ellipticity of the earth's orbit, as explained in theoretical astronomy.

(2.) The sun's motion in the ecliptic is not uniformly

eastward, but varying from east 23½ north, to east 23½ south. Hence, an equal amount of progress in longitude will not produce the same amount of progress in right ascension, throughout the year.

(3.) The celestial meridians approach each other as they recede from the equinoctial. Hence, the degrees of right ascension diminish, as they recede from the equinoctial, like the degrees of terrestrial longitude; and, therefore, a degree of longitude on a parallel of declination, as at the solstices, will make more than a degree of right ascension at the equinoctial.

These three causes coöperate in producing an inequality in the lengths of apparent solar days throughout the year.

The mean or average length of all the solar days in a year is a solar day, *mean time.* It is that which would be produced, if the daily increments of the sun's right ascension were the same throughout the year ; and is nearly four minutes (three minutes fifty-six seconds) longer than a sidereal day. A well regulated clock shows mean solar time.

The difference between mean and apparent solar time is the Equation of Time.

What is the mean increment of the sun's right ascension throughout the year ? (360° in 365¼ days = 59.13′ = 3 minutes 56 seconds in a day.)

In how many days does the sun pass through 30° longitude, from the 25° of Sagittarius ? — from the 25° of Gemini ? — When does the sun move fastest in the ecliptic ? — In passing from 15° in Pisces to 15° in Aries, how much right ascension does the sun make ? — from 15° in Gemini to 15° in Cancer ? — from 15° in

6*

Virgo to 15° in Libra ? — from 15° in Sagittarius to 15° in Capricornus ? — In what parts of the ecliptic and of the year does the obliquity of the ecliptic make the sun's motion in right ascension fastest ? — in what, slowest ? — In passing through 10° longitude, 5° each side of the solstices, how many degrees of right ascension does the sun make ?   (Prob. 5 – 10.)

PROBLEM 13.

To find the equation of time for any given day in the year.

Find it, by inspection, in the calendar, against the given day.

It may be found also by the scale of time in the analemma on the terrestrial globe, thus.

Bring the point indicative of the sun's declination to the meridian of the globe, then on the scale of time under the meridian is the equation of time for the given day.

Then, to reduce *mean* to apparent time, add the equations " clock two slow," and subtract the equations " clock too fast."

To reduce *apparent* to mean time, subtract the equations " clock too slow " and add the equations " clock too fast."

And to rectify the globe (prob. 12) for *mean* solar time, remove the sun's place as far west of its true place, in minutes of sidereal time, as are equal to the equations " clock too fast " ; or as far east as are equal to the equations " clock too slow."

Examples. When is the equation of time greatest, and when is it nothing ? — What is it, February 4th ? — August 15th, apparent noon, what o'clock is it ? — At what hour, mean time, is the sun on the meridian,

March 4th ? — November 3d ? — Rectify the globe for mean solar time, November 3d, and April 15th, &c.

___

Note. — In succeeding problems apparent time will be understood, unless mean time is expressed.

___

12. On the same day of every year, and at the same hour of the day, the sun or constellations appear in nearly the same position above the horizon of any given place.

PROBLEM 14.

To rectify the globe so as to represent the visible heavens, as seen at any given place, on any given day of the year, and at a given hour of the day.

Rectify the globe for the horizon of the given place, and for solar time on the given day. Turn the globe till the index points to the given hour.

In this position, the upper hemisphere of the globe represents the visible hemisphere of the heavens, as seen at the given place and time. And to a spectator at the centre of the globe, the sun and constellations appear in the same position above the horizon of the globe, in which they are seen above the celestial horizon of the given place, at the given time.

Examples. Rectify the globe to represent the visible heavens as seen at Boston, June 4th, at ten o'clock, A. M., and P. M. — What constellations will be visible this night, at this place, at midnight ?—what east and what west of the meridian, and what near the zenith ?

PROBLEM 15.

To determine the position of the sun, or any given fixed star, above the horizon, at any given place and time.

Rectify the globe so as to represent the visible heavens at the given place and time, and fasten the quadrant at the zenith.

Then, by problem 5th, find the altitude and azimuth, amplitude or bearing, of the sun or given star.

Examples. What are the altitude and bearing, amplitude or azimuth, of the sun, at the following places and times ? — at Philadelphia, August 6th, ten A. M. ? — at Quebec, June 22d, three, P. M. ? — at London, September 22d, six, A. M., and six, P. M. ? — at St. Petersburg, June 22d, at noon ? — same place, December 21st, at noon ? — at Quito, June 22d, and December 21st, at noon ?

In what part of the visible heavens will the constellation Orion appear, at New York, December 10th, at eleven, P. M. ?

PROBLEM 16.

The position of the sun, or any fixed star, above the horizon of a given place, being given, to find the hour of the day or night, the day of the year being given. Or, in the case of the sun, to find both the day and the hour.

Rectify the globe for the horizon of the given place, and for solar time on the given day, and fasten the quadrant of altitude at the zenith.

Turn the globe till the sun or given star has the given position in altitude and bearing, or amplitude, or azimuth. Then the index will point to the hour sought.

To find both the day and hour. Having rectified for the horizon of the given place, set the quadrant at the given point in the horizon, and, turning the globe, observe what point in the ecliptic intersects the quadrant

at the given altitude.. This point is the place of the sun on the day sought, whence the day can be known, There will be two such days, except when the sun is at the solstices. Then rectify the globe for solar time on the day thus found, and proceed to find the hour as above.

- *Examples.* What is the hour, May 10th, at Concord, N. H., when the sun is due southeast?—when southwest?—At Washington the sun is observed to be 10° in altitude, east of the meridian, September 1st; what hour is it then?—the same altitude west of the meridian?—At sea, in latitude 30 N., the sun is observed by the azimuth compass to bear E. 5° S.; what is the hour, July 4th?—At New York, the sun's position is observed to be 55° in altitude, and bearing S. 45° W.; what is the day and hour?

At what hour, December. 5th, will the star Procyon come to the meridian of Concord, N. H.?—At what hour, July 4th, will the constellation Cygnus be on the meridian of New York?—At what hour will Orion be S. W., at Burlington, Vt., January 1st?—What is the hour of the night, when the star Aldebaran is on the meridian of Boston, January 15th?—I observe the Pointers (α and β of Ursa Major) to range horizontally at Boston, March 10th; what hour of the night was it then?—At sea, October 3d, in latitude 40° N., the star Altair is observed to be due S. W.; what is the hour of the night?

13. The celestial meridian of any place is the XII. o'clock hour circle at that place; because the sun is on that meridian at noon.

In like manner, those celestial meridians which are situated at every 15° of right ascension distant from that meridian are, *westward*, the I., II., III., &c., o'clock hour circles ; and, *eastward*, the XI., X., IX., &c., o'clock hour circles ; because the sun is in these circles at those hours.   The half hour and quarter hour circles are at intermediate distances.

Let the globe be conceived as a hollow sphere. (Art. 1), and its axis made of metallic wire, or other opaque substance, which will cast a shadow from the sun's light.

Now, as the axis is a line lying in the plane of every hour circle (Prelim. 7), it is evident that the shadow of the axis will always be in the plane of the hour circle in which the sun is, and, as the sun passes on from one hour circle to another, the shadow of the axis will also move round in an opposite position and direction.

Thus the progress of the shadow of the axis among the hour circles will indicate the hours of the day. On this principle *Sun-dials* are constructed.   Let the globe, as above conceived, and rectified for the horizon of any given place, be placed with its meridian due north and south, and its horizon perfectly level, and then the sun shining on its axis would cause the shadow of the axis to move among the hour circles as above described ; and thus the globe would be a true sun-dial, a *spherical concave sun-dial* with the axis for the *style* or *gnomon*, the concave surface for the *face of the dial*, and the hour circles for the *hour lines*.

Let the plane of the horizon of the globe be conceived to be of wood, with the axis standing up, at the proper angle of inclination, from its centre ; then the shadow of the axis or gnomon will be projected on this plane towards those points of its circumference, where

the hour circles intersect it. Thus the plane of the globe's horizon becomes a *horizontal sun-dial*, in which the *hour lines* are the lines of intersection made by the hour circles with the horizontal plane.

Let the plane of the prime vertical (Art. 7) be substituted for the plane of the horizon, as above, and then we have the true conception of a *vertical sun-dial* fronting the sun at noon.

Take the plane of any other vertical in like manner, and then we have a vertical sun-dial turned so many degrees to the east or west, as the case may be.

Various other forms of the sun-dial have been devised, but the principle of construction and use is the same in all, the mode only of its application being changed. Some instruments called dials, as Ferguson's Card Dial, are merely contrivances for showing the hour by measuring the altitude of the sun, with some modification to make allowance for the sun's declination at the time.

PROBLEM 17.

To determine the angles which the various hour lines of a horizontal sun-dial make with the noon line, for any given latitude.

Rectify the globe for the horizon of any place in the given latitude. Bring the XII. o'clock hour circle to the meridian of the globe.

Then observe the azimuth of those points where the hour circles intersect the horizon of the globe. These azimuth angles are the hour-line angles required.

Examples. Find the hour-line angles for a horizontal sun-dial for a place in latitude 42°. — Draw the

hour lines for a horizontal sun-dial to be placed in the city of Troy, N. Y. — How must these dials be placed, to answer for the same parallels of south latitude ? — Can such dials be of any use at places under the equator ?

<center>PROBLEM 18.</center>

To determine the angles which the hour lines make with the noon line of a vertical sun-dial fronting in a given direction, for any given latitude.

Rectify the globe for the horizon of any place having the given latitude, bring the XII. o'clock hour circle to the meridian of the globe, and fasten the quadrant of altitude at the zenith and also successively at the given points of the horizon, so as to make it represent a portion of the given vertical.

Then observe at what degrees of zenith distance each of the hour circles intersects the quadrant on both sides of the meridian. These degrees measure the angles required.

As it is the southern half of the axis of the sphere which is represented by the style or gnomon of this dial, and the hour lines radiate from the centre downwards, properly the above hour-line angles should be taken on that portion of the prime vertical which is below the horizon of the globe.

But for the sake of greater convenience they are taken above it, where the angles are equal, being vertical angles to those required.

Examples. Find the hour-line angles made with the noon line of a vertical E. and W. sun-dial, for latitude 40° N. — Draw the hour lines on the face of a vertical sun-dial, fronting the S. 20° W., for Hanover, N. H.

How must such dials be placed, to answer for the same parallel of S. latitude ? — How many hours before and after noon will an E. and W. dial show ?

——

Note. — To find the half-hour lines, quarter-hour lines, &c., in both of the preceding problems, remove the XII. o'clock hour circle 7½°, 3¾°, &c., from the meridian of the globe, and then proceed as for the hour lines. The celestial meridians, which before were hour circles, thus become the half-hour, or quarter-hour, &c., circles. — How would you find the hour lines for every 20 or 10 minutes, or for every 4 minutes ?

N. B. — If the hour circles are not drawn on your celestial globe, the meridians on the terrestrial globe will represent them.

——

13. When the sun, or any star, begins to appear above the horizon in the east, it is then rising ; and when it begins to disappear beneath the horizon in the west, it is then setting.

The refractive power of the atmosphere on the rays of light causes the heavenly bodies to appear in the horizon, when their true place is about 34′ below it.

Hence, when any heavenly body is 34′, on a vertical, below the horizon of the globe, we are to consider it as then appearing in the horizon. Thus we make a correction for refraction in the hours of rising and setting of the sun or stars.

PROBLEM 19.

To determine the hours when the sun, or any given star, rises and sets on a given day, at any given place ; and also the lengths of daylight and darkness on that day.

7

Rectify the globe for the horizon of the given place, and for solar time on the given day.

Then bring the sun, or given star, to a position about 34' below the eastern part of the horizon, and the index will then point to the hour of rising.

Bring the sun, or given star, to a position about 34' below the horizon in the west, and then the index will point to the hour of setting.

The hour of sunrise doubled gives the length of the night, and the hour of sunset doubled gives the length of daylight.

Also the hour of sunrise subtracted from 12 gives the hour of sunset.

Examples. Find the hour of sunrise and of sunset, and the length of day and night, at each of the following places, — Boston, New York, Washington, Charleston, New Orleans, Cape Sable, Florida, Cuba, Venezuela, Quito, Rio Janeiro, Buenos Ayres, Cape Horn, Cape of Good Hope, Liberia, Borneo, Jerusalem, Paris, Berlin, St. Petersburg, &c., — on the following days at each place, March 21st, April 10th, May 15th, June 22d, July 20th, August 10th, September 22d, October 23d, November 30th, December 20th, January 15th, February 13th, &c.

On what points of the compass will the sun rise and set at Quebec on June 22d and December 20th ? — at London, same dates ? — When the sun is one hour high at Charleston, how high is it May 15th and October 20th ? — same for Edinburgh ? — At what hour and on what points of the horizon will the sun set to-day and rise to-morrow at the place of your residence ?

At what hour, at London, January 20th, does the

star Spica Virginis rise ? — At what hour, at New York, May 10th, will the star Aldebaran set ? — When will the star Markab, *α* in Pegasus, rise ? — At sea, latitude 30° N., the star Arcturus is seen rising, what is the hour of the night, February 20th ?

---

15. Those circles which the heavenly bodies apparently describe by their apparent diurnal revolutions are called their diurnal circles ; and that portion of each which is described above the horizon is called the diurnal arc.

The amount of the diurnal arc of each heavenly body is affected by the position of the sphere in reference to the plane of the horizon.

A Right Sphere is that portion of the sphere wherein all the diurnal circles are at *right angles* with the plane of the horizon.

A *Parallel Sphere* is that portion of the sphere wherein all the diurnal circles are *parallel* with the horizon.

An *Oblique Sphere* is that portion of the sphere in which all the diurnal circles are *oblique* to the plane of the horizon.

To what great circle of the sphere are all the diurnal circles parallel ? — In what line are the centres of all the diurnal circles found ? — Is either pole in any diurnal circle ? — As the heavenly bodies recede from the celestial equator, do their diurnal arcs enlarge or diminish, and in what ratio ? — In what ratio is the apparent velocity of the heavenly bodies in their diurnal arcs ?

PROBLEM 20.

To exhibit the phenomena of the diurnal revolutions

of the heavenly bodies in the various positions of the sphere, and to determine the length of the diurnal arcs.

In a *right sphere*, rectify the globe for the horizon of any place at the equator.

In a *parallel sphere*, rectify the globe for the horizon at either pole.

In an *oblique sphere*, rectify the globe for the horizon of the given place having a latitude either north or south.

Then the revolution of the globe on its axis will exhibit the diurnal phenomena sought.

To find the length of the diurnal arc of any given heavenly body, — rectify the globe for solar time, if the day be given, and find the hours of the rising and setting of the heavenly body, which gives the diurnal arc in time.

Or, bring the given heavenly body to the eastern horizon and set the index to XII., and turn the globe till the given heavenly body comes to the western horizon, and the index will then point to the number of hours of diurnal revolution above the horizon.

Examples in a right sphere. In what circle do the poles lie? — What circle passes through the zenith? — What is the zenith distance of every star, when on the meridian, compared with its declination? — With what circle does the VI. o'clock hour circle coincide? — with what the equinoctial? — How long does every fixed star continue above the horizon? — What portion of the diurnal circle does each describe above and below the horizon, no allowance being made for refraction? — and how much more with the correction for refraction? — On what point of the horizon does each rise and set, and what is the rising and setting amplitude of each, com-

pared with its declination, — say Aldebaran, Capella, Regulus, Sirius, *a* Ursæ Majoris, &c. ?

Examples in a parallel sphere. What point coincides with the zenith, and what circle of the sphere coincides with the horizon ? — *Where are the cardinal points of the horizon, and which direction is N. and S., and which E. and W. ?* — What is the altitude of every fixed star, compared with its declination, and does that altitude ever vary ? — What is the duration of all the diurnal arcs, and on what points of the horizon are they seen during an entire diurnal revolution ? — What fixed stars are always seen, and what are never seen, at the poles, allowance being made for refraction ?

Examples in an oblique sphere, say in latitude 45° N. What is the declination of the zenith ? — What circle of the sphere and what hour circle intersect the horizon in the east and west points ? — If a star has no declination, on what points of the horizon does it rise and set, and how long does it continue above the horizon ? — Are the diurnal arcs of those stars which have declination toward the elevated pole longer or shorter than 12 hours ? — those which decline towards the depressed pole ? — Which diurnal arcs are the longer, those having a greater or a less declination towards the elevated pole ? — those having a greater or less declination towards the depressed pole ?

Repeat the above questions for the position of the sphere in latitude 25° N., and in latitude 55° N., &c.

In which position of the sphere, with a greater or a less obliquity, do the diurnal arcs increase the fastest with the declination of the stars ? — Where are the longest

7*

diurnal arcs seen on the earth, — in higher or lower latitudes ? — What is the diurnal arc, in duration, of Cor Leonis, at Washington and Boston ? — of Spica Virginis, at Charleston and Quebec ? — at Rio Janeiro and Buenos Ayres ?

———

16. In an oblique sphere there is a space around the elevated pole within which the fixed stars are never seen to set, but to perform entire revolutions above the horizon. The circle which bounds this space is called the Circle of Perpetual Apparition, for the given place or latitude.

There is an equal space around the depressed pole within which the fixed stars perform entire revolutions below the horizon, and are never seen to rise. The circle which bounds this space is called the Circle of Perpetual Occultation, for the given place or latitude.

PROBLEM 21.

To determine the position of the circles of perpetual apparition and occultation for any given place or latitude.

Rectify the globe for the horizon of the given place or latitude. Then it will be seen that the polar distance of the circle of perpetual apparition, within which the stars revolve entirely above the horizon, is equal to the elevation of the pole, which is equal to the latitude of the place of observation.

The circle of perpetual occultation has a polar distance equal to this, around the opposite pole.

Examples. What is the *declination* of the circles of perpetual apparition and occultation, at Jamaica, W. I. ?

— at Charleston ? — at New York ? — at Iceland ? — at Cape Horn ? — at sea, in latitude 50° N. ? — 60° S. ? What constellations are never seen at Boston, and what are always seen there at night in a clear sky ? — Between what circles of declination are the stars situated which are seen to rise and set at New Haven ?

Examples. *Vice versâ.* In what latitude can I see the circle of perpetual apparition at 10° declination N. ? — at 23½° co-declination N. or S. ? — How far southward from the north pole must I travel to see the whole of Ursa Major above the horizon during an entire sidereal day ? — How far southward must I sail to see any of the constellations called the Southern Cross ? — How far, to see it make an entire revolution round the south pole ? — What correction is to be made for refraction, in these problems or questions ? — How far around both poles can I see, when at the earth's equator ?

17. The phenomena caused by the diurnal revolution of the sun, as seen on the same day at different places, are affected by the position of the sphere at each place. And the phenomena, as seen at the same place on different days of the year, are affected by the varying declination of the sun at the different times.

In a right sphere, or at the equator, the proportion between daylight and darkness is the same at all times.

In an oblique sphere, the disproportion between daylight and darkness, on the same day, increases with the obliquity of the sphere ; that is, with the latitude of the place.

And in a parallel sphere, the whole 24 hours of any given day is either all darkness or all daylight, — the

former, when the sun's declination is towards the depressed pole ; the latter, when his declination is towards the elevated pole.

When the sun's declination is nothing, the duration of daylight and that of darkness are the same, and equal to each other, in all parts of the world.

When the sun's declination is toward the elevated pole in an oblique sphere, the duration of daylight is greater than that of darkness. And when his declination is toward the depressed pole, the reverse takes place.

Moreover, when the sun, by reason of his varying declination, comes within the circle of perpetual apparition at any place, and while he continues within it, there is perpetual daylight, without any darkness, at that place.

And when he enters, and while he continues, within the circle of perpetual occultation, there is perpetual darkness at that place.

Examples, in a right sphere, or at all places on the earth's equator. — What are the hours of sunrise and of sunset, and the relative lengths of day and night, on any day, or all days of the year, say June 21st, &c. ? — On what points of the horizon does the sun rise and set, at the equinoxes ? — On what, at the solstices ? — On what, January 1st, April 10th, August 1st, &c. ? — What is the sun's rising and setting amplitude, when his declination is 10° N.? — 18° N.? — 23½° N.? — 14° S.? — 20° S. ? — when his declination is any given degree N. or S.? — What are the sun's meridian altitude and zenith distance, when his declination is 10° N.? — 18° N.? — 23½° N.? — 14° S.? — 20° S.? — and when his declination is any given degree N. or S. ? — Any one of these

five being given, — the sun's rising or setting azimuth and amplitude, meridian altitude, zenith distance on the meridian, and declination on any given day, how are the others known ?

Examples, in an oblique sphere, or at all places between the equator and the poles. At what hours, and on what points of the horizon, does the sun rise and set, and what is the relative length of daylight and darkness, May 1st, at the following places, — Quito, Mexico, New Orleans, Washington, New York, Montreal, Edinburgh, Archangel ? — At what hours, and on what points of the horizon, does the sun rise and set, and what is the relative length of daylight and darkness, March 21st, May 10th, June 22d, August 1st, September 22d, November 5th, December 20th, January 15th, — at Havana, in Cuba, — at Charleston, — at Cincinnati, &c. ? — What days of the year have the greatest proportion of daylight in northern latitudes ? — and in southern latitudes ? — At what points in the ecliptic is the sun then ? — What is the length of the longest daylight, at the following places, — Cape Sable, in Florida, — Philadelphia, — the northeast point of Maine, — the Shetland Islands, Scotland ? — What is the length of the longest night at the same places ? — What is the difference between the longest and shortest days at Borneo ? — Calcutta ? — Cairo ? — London ? — New Orleans ? — Portland, in Maine ? — St. Petersburg ?

Examples, in a parallel sphere, or at either pole of the earth. — When the sun's declination is south, is it daylight or darkness at the north pole ? — When his

declination is north ? — How is this at the south pole ? — Allowing for the effect of refraction, what is the sun's declination when he first appears in the horizon of the north pole ? — On what points of the horizon is the sun seen, and at what altitude, during an entire revolution, May 1st, June 22d, August 6th ? — How many degrees of azimuth does the sun traverse during every hour of the 24 ? — *When is it noon at the poles ?* — How high above the horizon at the north pole is the sun, when his declination is 10° N. ? — 18° N. ? — 23¼° N. ? — When his declination is north increasing, is the sun's altitude decreasing or increasing above the horizon at the north pole ? — When his declination is decreasing, what then ? — Describe the nature of the sun's apparent path, in his diurnal revolutions, while above the horizon of either pole.

Has a parallel sphere ever been seen by man ?

What proportion between the amount of light and darkness, in a year, at the equator, any parallel of latitude, and at either pole, if we allow nothing for refraction and the sun's unequal motion in the ecliptic ? — Which hemisphere of the earth, the northern or the southern, has actually the greatest share of light in any year ?

PROBLEM 22.

To determine in what latitudes on the earth the sun is seen above the horizon during the 24 hours of a given day.

Find the sun's declination on the given day, and elevate the pole towards which he declines equally to the co-declination. This elevation of the pole is equal to the latitude from which to the pole the sun is seen during the entire diurnal revolution on the given day.

Or, more briefly, the sun's declination on the given day is equal to the polar distance on the earth within which the sun is seen above the horizon during the 24 hours of the given day.

What is the polar distance of the circle of perpetual apparition for any given latitude ? — What must be the polar distance or co-declination of the sun, when he comes within this circle ?

What is the *declination* of the circle of perpetual apparition for any given latitude ?

Examples. Where is the sun seen, during the whole 24 hours, above the horizon, on May 10th, June 21st, August 15th, September 22d, November 1st, January 15th ? — Where is he not seen at all on the same days ?

PROBLEM 23.

To determine when and how long the sun is seen perpetually above the horizon of a given place within the arctic or antarctic circles. And also when and how long he is not seen at the same place.

Rectify the globe for the horizon of the given place. Then observe what portion of the ecliptic revolves above the horizon, and (on account of refraction) 34′ below it. Find on what days the sun enters and leaves this portion of the ecliptic, and how long he continues in it. These are the days, and this the space of time, required.

It will be seen that the co-latitude of the given place is equal to the declination which the sun must have when he is at its circle of perpetual apparition ; or, to correct for refraction, the co-latitude, *minus* 34′, is equal to this

declination. With this declination, find the days and the space of time required.

To find when and how long the sun is not seen at all at the given place, rectify for the same parallel of opposite latitude, and proceed as above.

Or, with the degree of declination found as above, but of an opposite kind, find the days and time required.

Examples. At Spitzbergen, latitude 80° north, when, and how long, is the sun seen perpetually above the horizon ? — When, and how long, is he not seen at all there ? — At Melville Island, when does the season of perpetual day begin and end ? — and when that of perpetual night ? — What portions of the year intervene between the seasons of perpetual day and night ? — What days of the year are the mid-days of perpetual day and perpetual night, in polar regions ? — Is it perpetual day or night at Melville Island, May 10th, November 20th ? — What season of light or darkness is it there, August 20th ? — November 15th ?

What are the sun's altitude and bearing for every three hours from noon, April 16th, to noon next day, — May 20th, June 21st, July 15th, at Spitzbergen ? — When the sun is seen on the meridian in the north, in arctic regions, what is the hour ? — When seen on the meridian in the south, what o'clock is it ? — Same questions in antarctic regions.

How many days of the year is the sun seen at the north pole ? — How many at the south pole ? — How many days is he seen at both places *at once ?* — Why ?

---

18. Twilight may be considered as a prolongation of imperfect daylight. While the sun is within about 18°

below the horizon, some twilight may be seen, more or less, according to the sun's distance below the horizon. (Lessons on Ter. Globe, art. 12.)

The duration of twilight is affected by the same causes which affect the duration of daylight at different times and places. (Article 16.)

Particularly in high latitudes, the reign of perpetual daylight is extended, and that of perpetual night greatly mitigated, by long seasons of twilight.

While the sun is not more than 18° from the circle of perpetual apparition at any given place, there will be twilight during the whole night there.

And while the sun is not more than 18° within the circle of perpetual occultation at any given place, there will be some twilight enjoyed, for a season, before and after the hour of noon.

And while the sun is within both these limits, at any given place, there will be twilight during the whole 24 hours there.

PROBLEM 24.

To determine the hour when twilight begins in the morning and ends in the evening, and also the point of the horizon where it may be seen brightest, at any time during its continuance, for any given place and day of the year.

Rectify the globe for the horizon of the given place, and for solar time on the given day, and fasten the quadrant at the zenith.

Turn the globe till the sun is about 18° below the horizon, as measured by the quadrant, at the eastern or western sides of the horizon.

The index will then show the hour of the beginning

8

of twilight at the horizon in the east, or the hour when it vanishes at the horizon in the west.

And the point of the horizon which is intercepted by the quadrant, in measuring the distance of the sun below the horizon, is the point where the middle and brightest part of the twilight may be seen.

Examples. When does the day begin to dawn at Edinburgh, December 20th, and June 21st ? — at New Orleans, July 4th ? — at Quebec, August 1st ? — When does evening twilight disappear at Charleston, May 15th? — When does dark night set in at Boston, June 1st ?

On what points of the horizon do the dawn and the evening twilight begin and end, at Montreal, May 31st? — at London, June 21st ?

At Halifax, the middle and brightest part of the dawn is observed to be 20° north from the point where the sun is to rise, June 21st ; what hour is it then, and how long before sunrise ? — How long is it after sunset, when the middle of the twilight is seen 15° N. of the place of sunset in latitude 51° N., on the 1st of August ? ·

PROBLEM 25.

To determine when, and how long, twilight may be seen at the hours of midnight and of noon in a given latitude, in arctic or antarctic regions.

Rectify the globe for the horizon of any place in the given latitude.

Then, as the globe revolves, observe what portion, or portions, of the ecliptic pass the meridian within 18° below the horizon in the north, for a northern latitude, — but in the south, for a southern latitude. While

the sun is in this portion, or these portions, of the eclip-tic, twilight may be seen at the hour of midnight.

Observe, also, what portion or portions of the eclip-tic pass the meridian within 18° below the horizon in the south, for a northern latitude, — but in the north, for a southern latitude. While the sun is in this portion, or these portions, of the ecliptic, twilight may be seen at the hour of noon, in the given latitude.

Examples. When, and how long, is twilight seen at the hour of midnight in latitude 48½° N. ? — in latitude 66½° N. ? — latitude 80° N. ?

When, and how long, is twilight seen at the hour of noon in latitude 75° N. ? — latitude 87° N. ? — How long does twilight continue at the north pole ? — When, and how long, is no twilight seen there ?

Describe the various phenomena of daylight, twi-light, and darkness, through all their changes, for a year, beginning June 21st, as seen at Melville Island, in lati-tude 75° N.

PROBLEM 26.

To find in what latitudes twilight may be seen on a given day of the year, at the hours of noon and mid-night.

Find the sun's place in the ecliptic on the given day, and mark it. Then

I. For northern latitudes.

(1.) Elevate the north pole, till the sun, as the globe revolves, passes the meridian just 18° below the horizon at the north; and observe the degrees of this elevation of the pole. If, with this elevation, the sun passes the meridian, at the south, above the horizon, then elevate

the pole farther, till the sun passes the meridian just in the horizon at the north ; and observe the degrees of this elevation.

These two elevations of the pole are severally equal to the two parallels of north latitude on the earth between which twilight is seen at the hour of midnight, and consequently from sunset to sunrise on the given day.

(2.) Elevate the north pole, till the sun, as the globe revolves, passes the meridian just 18° below the horizon at the north ; and observe the degrees of this elevation. If, with this elevation, the sun passes the meridian within 18° below the horizon at the south, elevate the pole farther till the sun passes the meridian just 18° below the horizon at the south ; and observe the degrees of this elevation.

These two elevations are severally equal to the latitude of two parallels between which twilight is seen both at the hour of noon and of midnight on the given day, that is, during the whole 24 hours of perpetual night.

(3.) If, with the pole elevated to the zenith, the sun passes the meridian more than 18° below the horizon, then elevate the north pole till the sun passes the meridian just in the horizon at the south ; and observe the degrees of this elevation. Again elevate the pole till the sun passes the meridian just 18° below the horizon at the south ; and observe the degrees of this elevation.

These two elevations of the pole are severally equal to the latitude of the two parallels between which twilight is seen at the hour of noon only. And from the highest of these parallels to the north pole of the earth, no twilight is seen at any hour on the given day.

II. For southern latitudes.

Transposing the terms north and south, proceed as for northern latitudes.

Examples. In what northern latitudes is twilight seen, and at which hour, noon or midnight, when the sun's declination is 10° N. ? — In what southern latitudes, at the same time ? — In what latitude N. is twilight seen all night, when the sun's declination is 23½° N., the maximum ? — when 5° S. ? — In what latitude N. is it seen at noon, at the same time ?

Where is twilight seen at noon and midnight, August 1st ? — Where seen in the north, May 10th ? — Where seen in the south, November 10th ?

How far round each pole is there no twilight, during the reign of perpetual night there ? — On the 15th of July, what parts of the earth have perpetual daylight ? — what have perpetual night ? — what have twilight at the hour of noon ? — and what at the hour of midnight ? — and at what parallel of terrestrial latitude is the sun vertical at noon ?

Describe the various phenomena of daylight, twilight, and darkness, in the various parts of the earth, *to-day.*

———

19. The Moon, like the sun, has an apparent motion eastward among the fixed stars, making a complete revolution round the sphere in about 27 days 8 hours (27.32 days). This motion is real, as well as apparent.

The motion of the moon in her orbit or path is not uniform. As in the case of the sun (Art. 11), this arises from the ellipticity of the moon's orbit.

When the moon is in *apogee* (that point of her orbit farthest from the earth) her daily motion is less than

12°; when in *perigee* (that point nearest to the earth), her daily motion is nearly 14½°. The mean motion is 13° 10'. The points *apogee* and *perigee* are not fixed points, — they shift their position eastward at the rate of 3° in every revolution of the moon round the sphere, making the circuit of the sphere in about 9 years.

Besides this irregularity, there is a great number of others which are less in amount, all of which have been calculated by astronomers. The results of their calculations constitute the Lunar Tables.

The moon's apparent path is a great circle of the sphere, which crosses the ecliptic at an angle of about 5° (5° 8' 48") in two opposite points, called the *ascending node*, which the moon passes in crossing to the north side of the ecliptic, and the *descending node*, which she passes in crossing to the south side.

The moon's nodes are not fixed points, — they shift their position westward in the ecliptic at the rate of 19° 35' in a year.

As the position of the moon's path is thus constantly shifting on the sphere, it is not represented on the globe by a permanent circle, like the ecliptic.

Hence, the moon's place on the globe is to be found by her latitude and longitude, or declination and right ascension; as given in the Almanac, or calculated by means of the Lunar Tables. The same may be found also approximately, the moon's age being given.

How many degrees does the moon move in a day, at her mean rate? (360° ÷ 27.32.) — How many in an hour? — In apogee and perigee, what is her hourly motion?

What is the maximum of celestial latitude which the

moon can ever have ? — the maximum of declination ? — Can her latitude ever be south and her declination north at the same time ? — In what points is the moon, when her latitude is nothing ? — Which node has the moon passed, when her latitude is north ? — when it is south ?

PROBLEM 27.

The moon's place being given, in latitude and longitude, or in declination and right ascension, for a given day and hour, to find the hour when the moon rises and sets, when she souths, as also her azimuth, amplitude, and altitude at a given time, for any given place.

Rectify the globe for the horizon of the given place, and for solar time on the given day.

Then mark the moon's place at the given hour of the day, but remembering for every hour previous to the given hour to remove her place 33' westward, and for every hour subsequent to the given hour 33' eastward.

With this modification, find the hour of rising, culminating, and setting, also the azimuth, amplitude, and altitude, precisely as these are found in relation to the sun by preceding problems.

—

Note. — In determining the moon's apparent position in the horizon, a correction is required for parallax. Parallax is the apparent change of place in altitude which the heavenly bodies have, as seen from the earth's surface and its centre ; it causes them to appear lower than their true place, as seen from the earth's centre. For the moon in the horizon, the angle of parallax amounts to 57', so that it more than counterbalances the effect of refraction (34'). Hence, the moon is to

be considered in the apparent horizon when (57′— 34′) 23′ above the horizon of the globe, which represents the true horizon as seen from the earth's centre.

Examples. The moon's longitude 100°, latitude 2° N., at noon, January 15th, at Boston ; find when she rises, souths, and sets ; also her amplitude at rising and setting. (Rises about three, P. M., E. 35° N., souths at half past ten, P. M., sets about seven, A. M., next morning, in W. 31° N.) — Find the same, same day, at the Shetland Islands.

The moon's place in longitude 200°, latitude 4° S., and the sun's place 10° in Libra, at noon, New York ; at what hour will the sun and moon set there ?

The moon's place in 0° of Cancer, latitude 5° N. ; how high is the moon on the meridian of a place in N. latitude 28½° ? — in N. latitude 42° ? — The moon's place being 0° in Capricorn, latitude 5° S., what is the moon's meridian altitude in latitude 42° N. ? — in latitude 51° N. ? — 61½° N. ? — The moon's declination being at the maximum, 28½° N., how far around the N. pole does she shine during the whole 24 hours ? — In what latitudes is the moon seen within the circle of perpetual apparition, when her declination is 15° N. ? — 25° N. ? — 10° S. ?

PROBLEM 28.

The moon's distance from a node being given, to determine her latitude.

Bring the north ecliptic pole to the meridian of the globe, and fasten the quadrant over the pole. Elevate the N. pole of the globe (71½°) till the ecliptic is 5° above the horizon at the north.

In this position of the globe the horizon of the globe coincides with the moon's path, and the points where it is intersected by the ecliptic represent the moon's nodes. The distance of the moon from a node may be measured on the ecliptic, or on the horizon considered as the moon's path, and her latitude by the degrees on the quadrant when set at the given distance from the node.

Examples. The moon 90° past her ascending node, what is her latitude ? — 20° — 45° — 60° past the same, what is her latitude ? — When 30° — 120° past her descending node, what is her latitude ?

PROBLEM 29.

The position of the moon's nodes being given for any given time, to represent the moon's path on the globe.

Mark the given places of the nodes on the ecliptic, and also two points equally distant from them, giving that eastward of the ascending node a latitude of 5° north, and that eastward of the descending node a latitude of 5° south. Then fasten a piece of thread (of elastic material) round the globe, and passing through these four points. This thread will represent the moon's path in position at the given time.

Examples. The moon's ascending node being in longitude 3 signs, represent her path in position at the time. — The ascending node being in Leo 15°, and the moon 60° past it, what is her latitude ? — The moon being in the same position, at what hour does she rise at Boston, January 1st ?

20. When the sun and moon have the same longitude, the moon is·said to be in *conjunction* with the
- sun ; — when their longitudes differ 180°, she is in *opposition* ; — when their longitudes differ 90°, she is in
quadrature.   At these points and the intermediate middle points the moon exhibits her *phases*, as new moon,
full moon, half moon, and quarters, either horned or gibbous.

The revolution of the moon, from one conjunction
with the sun to the next conjunction, is called her
synodic revolution, and it is completed in about 29½
days (29.53).   This is more than her *sidereal revolution*, because the sun is moving at the same time, in
the same direction with the moon, at the rate of nearly
1° in a day.

Which moves fastest, the sun or moon, in their apparent course round the earth ? — How many degrees
does the moon gain on the sun in a day ? (13⅕° — 1°=)
12⅕°.   (Art. 18.) — How many degrees must the moon
gain upon the sun from the time of conjunction, to be
in conjunction again ? — How long will it take the
moon to gain this much on the sun ? (360° ÷ 12⅕° =)
29½ days. — Through how many degrees of longitude
does the moon pass from one conjunction to another ?
(13⅕° × 29½ = 388½°.)   When the sun is in the
southern signs, in what signs do the full moons occur ?
— Which circumpolar regions, those where perpetual
night reigns, or those where perpetual day reigns, enjoy the light of the moon at full ?

PROBLEM 30.

The moon's age being given and the day of the year,
to find the moon's place nearly.

Reckon forward from the sun's place on the given day, as many times 12¼° as there are days in the moon's age. This will give the moon's place in longitude, or nearly so.

Examples. The moon's age is 8 days, June 1st; what is her place in longitude? — The moon's age, August 10th, at noon, is 14 days 3 hours, her latitude 3° S.; find her place. — What is the difference of longitude between the sun and moon, the moon being two days old? — six days? — twenty-one days? — The moon eight days old, and 45° from her ascending node, find her place.

Find the place of full moon, December 20th, her latitude being 5° N.; — June 21st, her latitude being 5° S. — The moon is seen half-full, and waxing, September 22d; where is her place?

At the time of the autumnal equinox, where is the full moon, called in England the Harvest moon? — Find the hour of the harvest moon's rising in England for three days before and three days after the full. — Why are the hours of the moon's rising so nearly the same on these days? — If the moon is at or near the ascending node at the full, what effect has this on the time of the harvest moon's rising? — if near the descending node, what effect has this? — On what points of the horizon does the harvest moon rise on these evenings?

Find the same circumstances for the full moon at the time of the vernal equinox, and state the difference in the result from that of the harvest moon. — Where is the benefit of the harvest moon enjoyed the most, in higher or lower latitudes? — Where is there the most need of it?

At the winter solstice, December 20th, how far around the north pole of the earth does the full moon shine during the whole 24 hours, her latitude being 5° N. ? — her latitude 5° S. ? — How far from the north pole of the earth is the new moon seen within the circle of perpetual apparition, her latitude at full being 5° N., about the time of the winter solstice ? — Within about what distance around the north pole of the earth does the moon shine constantly above the horizon during a whole lunation, her latitude at conjunction being 5° N., about the time of the winter solstice ? — During what portion of the same lunation is the moon constantly above the horizon, at and within the arctic circle, about the 20th of December, her latitude at full being 5° N.?

———

21. When the moon is within 17° of either of her nodes at the time of conjunction with the sun, she intercepts the sun's light from a portion of the earth, so that the sun is hid wholly or partially from the view of the inhabitants for a time. This is a solar eclipse.

When the moon is within 12° of either of her nodes at the time of opposition to the sun, the earth intercepts the sun's light from the moon, — except so much as is refracted by the earth's atmosphere. This is a lunar eclipse, and it is visible wherever the moon is visible at the time.

To calculate the elements of solar and lunar eclipses is a problem not comprehended in the plan of this work.

PROBLEM 31.

The time and place being given when and where an eclipse of the moon will be visible, to find in what parts of the earth it will be visible at the same time.

By the Terrestrial Globe. Find where the sun is vertical at the given time of the eclipse ; find also its antipodes ; *there the moon is vertical at the same time.* Bring the place where the moon is vertical to the meridian, and elevate the nearest pole equal to its latitude. Then the horizon of the globe becomes the circle of lunar illumination, and to all places above it the moon is visible and seen eclipsed at the given time. In all places at the western verge of this circle, the moon is seen rising eclipsed ; in all places at the eastern verge of the same, the moon is seen setting eclipsed ; and in all places at the meridian of the globe, the moon is seen eclipsed on the meridian.

See problems 11 and 12 on the terrestrial globe, also problem 13.

Examples. An eclipse of the moon is seen at Burlington, Vt., August 13th, 1840, — the beginning at 1 hour 5 minutes, the greatest obscuration at 2 hours 30 minutes, and the end at 3 hours 55 minutes, in the morning ; — at what other places of the earth are the beginning, the middle, and the end of this eclipse visible ?

A total eclipse of the moon visible at Boston, — total obscuration at 8 hours 34 minutes, the middle at 9 hours 22½ minutes, and the end at 10 hours 11 minutes, February 5th, 1841 ; — where is it seen eclipsed in the east, in the west, and on the meridian ?

———

22. There are a few stars whose apparent motions are so devious and irregular, that they have received the name of *planets*, or wandering stars. Their apparent courses are sometimes direct in the order of the signs,

and sometimes retrograde; their apparent motions are
sometimes slow, sometimes faster, and sometimes sta-
tionary, or nearly so, on the surface of the celestial
sphere.

These irregular movements of the planets are, how-
ever, merely apparent, being caused by the motions of
the earth, from which we view them, combined with
the proper motions of the planets round the sun as their
centre.

The motions, courses, and positions of the heavenly
bodies, as seen from the earth, are called their *geocentric*
motions, courses, and positions;—as seen from the sun,
they are called their *heliocentric* motions, courses, and
positions. The latter are deduced by calculation from
the former.

The geocentric and heliocentric positions of the fixed
stars are the same, because of their immeasurably great
distance from us. But the planets, being situated at
distances which can be measured by their horizontal par-
allax and otherwise, have geocentric and heliocentric
motions, courses, and positions different from each oth-
er. And while their geocentric movements are as devi-
ous as above described, their heliocentric movements
are found to be as harmonious and uniform as those of
the earth or moon.

Hence, the geocentric position of a planet at any
time, or its apparent course for any given space of time,
can be indicated on the globe only by its latitude and
longitude, or its right ascension and declination, as given
in a correct almanac.

PROBLEM 32.

To determine the apparent place of a planet at any

given time ; its declination and right ascension, or lati-
tude and longitude, being given ; or the day and hour
when it is on the meridian of any place being given, with
its declination.

When the declination and right ascension, or latitude
and longitude, are given, find its position by problem 2
or 9.

When the day and hour of its passing the meridian are
given, with its declination, — rectify the globe for solar
time, mean or apparent, as the given case may be, on
the given day.   Turn the globe till the index points to
the given hour, then under the given degree of declina-
tion is the position of the planet at that time.

Or, by arithmetic, reduce the given hours and min-
utes before or after noon into degrees of right ascen-
sion.   Add this to the sun's right ascension on the giv-
en day, if the hours be after noon ; and the sum is the
planet's right ascension at the given time.   Or, if the
hours be before noon, subtract it from the sun's right
ascension, and the remainder is the right ascension of
the planet.   Then, with this and the given declination,
find the position as above, by problem 2.

Examples.   The right ascension of Venus is 30°, and
declination 12° N. ; find and mark her apparent place. —
She is on the meridian at 19 minutes past noon, mean
time, January 1st, her declination being 23° 31' S. ;
find and mark her place. — The planet Jupiter is on the
meridian, December 19th, at 8 hours 45 minutes in the
morning, his declination being 14° 7' S. ; find and mark
his place.

<div align="center">PROBLEM 33.</div>

To describe the apparent path of a planet in the

sky, its position at a sufficient number of times being given.

Find and mark on the globe, or on a *planisphere*, its position at each of the given times, by problem 32. Then a line traced through these positions, in their order, will be a representation of the apparent path of the planet during the given space of time.

———

Note. — A portion of a planisphere, sufficiently extensive and correct for laying down the apparent path of a planet, may be easily made thus.

If the successive positions of the planet are given in right ascension and declination, draw a straight line from right to left on your paper, to represent the Celestial Equator or Equinoctial, and divide it into 360 equal parts for degrees of right ascension. Or, if the planet's path for less than a year be required, a shorter line and fewer degrees will be required. Then, at each given degree of right ascension, the correspondent degrees of declination are to be measured on lines at right angles to the equinoctial, northern declination being set off above the equinoctial line, and southern declination below it. An off-set scale, such as surveyors use in protracting maps, will be convenient for setting off the declinations.

If the successive positions of the planet are given in longitude and latitude, then the line drawn from right to left represents the ecliptic, and is to be divided accordingly into signs and their degrees ; and north latitudes are to be set off above, and south latitudes below, this line. As the latitude of the planets is never great, except that of the recently discovered ones, this is the preferable form of a planetary map or planisphere.

If the off-set scale for declinations is so made that 60° on it are equal to 59° on the equinoctial, the error which arises in the above construction, by making the degrees of right ascension all equal in every parallel of declination, will be partially compensated. Perfect accuracy will be attained at the parallel of 15° on each side of the equator.

Examples. In the American Almanac is given the " passage of the meridian (mean time) and declination of the planets," for the 1st, 7th, 19th, and 25th days of each month, — the meridian being that of Washington. With these elements given, it is required to trace the apparent paths of the planets for one year, — those, at least, of Mercury, Venus, Mars, and Jupiter.

Trace the apparent path of " Gambart's comet," from its apparent right ascension and declination, as given in the American Almanac for 1839, p. 38.

23. The distance in longitude of the planets Mercury and Venus from the sun, either to the east or west, is called the *Elongation* of the planet east or west. The elongation of Mercury is never more than about 28°, and of Venus about 47°. The other planets are seen at all distances, up to 180°, from the sun.

When Mercury or Venus is in conjunction with the sun passing from the east to the west, it is called the *inferior* conjunction ; when in conjunction passing from the west to the east of the sun, it is called the *superior* conjunction. The apparent diameter of the planet's disc, as seen through a telescope, is greatest at the inferior, and least at the superior conjunction. Hence the

planet is at its least distance from the earth at the former epoch, and at its greatest distance at the latter epoch.

While Venus is east of the sun, she is seen above the horizon soon after sunset, and hence is called the Evening star.   While west of the sun, she is seen above the horizon before the sun rises, and hence is called the Morning star.

The time which elapses from the conjunction of a planet till the same occurs again is called the *synodic* period of the planet.   The synodic period of Mercury is 115.877 days ; that of Venus 584 days.

Examples.   When, by the almanac this year, is Venus at her greatest eastern and western elongations ? — when at her inferior or superior conjunction ? — What is her celestial latitude at conjunction ? — When is Mercury at his greatest elongation this year ?

Find and mark the apparent places of all the planets at 9 o'clock this evening. — Which of them will be then visible, and where, above the horizon of Washington ? — When will Venus rise at Boston, June 3d, this year ? — What planets would be seen at noon this day, at New York, but for the superior light of the sun ?

———

24. The stars emit their light to our eyes in the daytime, as well as in the night ; but the stronger light of the sun so affects our eyes, that we cannot see them amid the brighter effulgence of his rays.   Hence the time for studying the starry sky must be the nighttime.

The pupil should first of all become perfectly familiar with the positions of the great circles of the sphere in the sky, at the place of his residence, as well as on

the globe. He should also learn to judge accurately, by the eye, the correct distance, in degrees, from one star to another, by making some few cases very familiar to his eye and memory, as the distance of Castor and Pollux apart, the distance between the Pointers, &c., as measured on the globe. Equally important is it that he learn to estimate distances on a vertical, either from the zenith or the horizon, as also azimuth distances, by the eye.

Each constellation is to be recognized by its principal stars, and by its position above the horizon, as determined by the globe for any given time.

Perhaps the best way of procedure is for the pupil to draw a map, on a large scale, of each constellation, filling it up with the stars in the order of their magnitudes, as fast as he learns to recognize them in the sky and to give them their names.

As far as convenient, it is desirable to become acquainted first with the zodiacal constellations, Aries, Taurus, &c., then those north and south of them, as far as the circles of perpetual apparition and occultation, and those within the circle of perpetual apparition at the place of the pupil's residence. Finally, those constellations which are seen at the same degree of opposite latitude on the earth, or within the circle of perpetual occultation, may be studied on the globe.

PROBLEM 34.

To determine on what day of the year a given star or constellation may be first seen in the east, and when it may be last seen in the west soon after sunset, and during what part of the year it may be seen above the horizon of a given place in the evening.

Rectify the globe for the horizon of the given place, and bring the given star or constellation to the eastern horizon so as to be just above it. Then observe what point of the ecliptic is about 5° or 6° below the horizon in the west. Find on what day the sun is in that point of the ecliptic. It is the first of the days required.

Then bring the star or constellation to the western part of the horizon so as to be just above it ; and observe what point on the ecliptic is about 5° or 6° below the horizon in the west. Find on what day the sun is in that point, which will be the second of the days required.

From the first to the second of these days the star or constellation may be seen above the horizon of the given place, in the evening.

By a similar process, the same particulars may be found for the morning.

Examples. During what part of the year will Leo be seen at Boston in the evening ? — Spica Virginis, at New York ? — Castor and Pollux, at Philadelphia ? — Orion, at Burlington, Vt. ? — Sirius, at this place ? — What constellations may be always, and what never, seen at this place ?

PROBLEM 35.

To determine on what day of the year a given star will be on the meridian at a given hour.

Bring the given star to the meridian of the globe, and set the index to the given hour. Turn the globe till the index points to XII. noon. Then the sun's place and the day of the year required will be found at the meridian, marked on the ecliptic.

Examples. On what day of the year does *a* in Orion come to the meridian at 9 o'clock, P. M. ? — When does Caput Medusæ come to the meridian at 8¼ o'clock, P. M. ? — When Regulus, at 10 o'clock, P. M. ? — When Spica Virginis, at 3 o'clock in the morning ? — On what day is there some part of Taurus on the meridian ?

PROBLEM 36.

To rectify the globe for the study of the starry sky at any given time and place.

First find and mark the positions of the planets which may be visible at the given time. Then rectify the globe so as to represent the visible heavens as seen at the given place and time (Problem 14) ; and set the globe with its meridian north and south, and its horizon as nearly level as may be, with its cardinal points directed towards the same points in the heavens.

Thus placed, a line from the centre of the globe through any star or point on its surface will be directed to the star or point in the sky represented by it ; and the altitude, azimuth, or bearing of any star then seen in the sky may be determined by means of the globe ; — or, these elements being determined by a *Theodolite,* or other suitable instrument, in the sky, the star and its name may be found on the globe by the elements of its position thus found. (Problem 5.)

Examples. Rectify the globe for the study of the constellations, this day, at 9 o'clock, mean time, at this place. — What constellations are then on the meridian ? — In what is the zenith ? — What are rising south of the east, and what north of the east ? — What are near

setting, south and north of the west cardinal point ? —
What are within the circle of perpetual apparition ? —
In what points does the ecliptic intersect the horizon
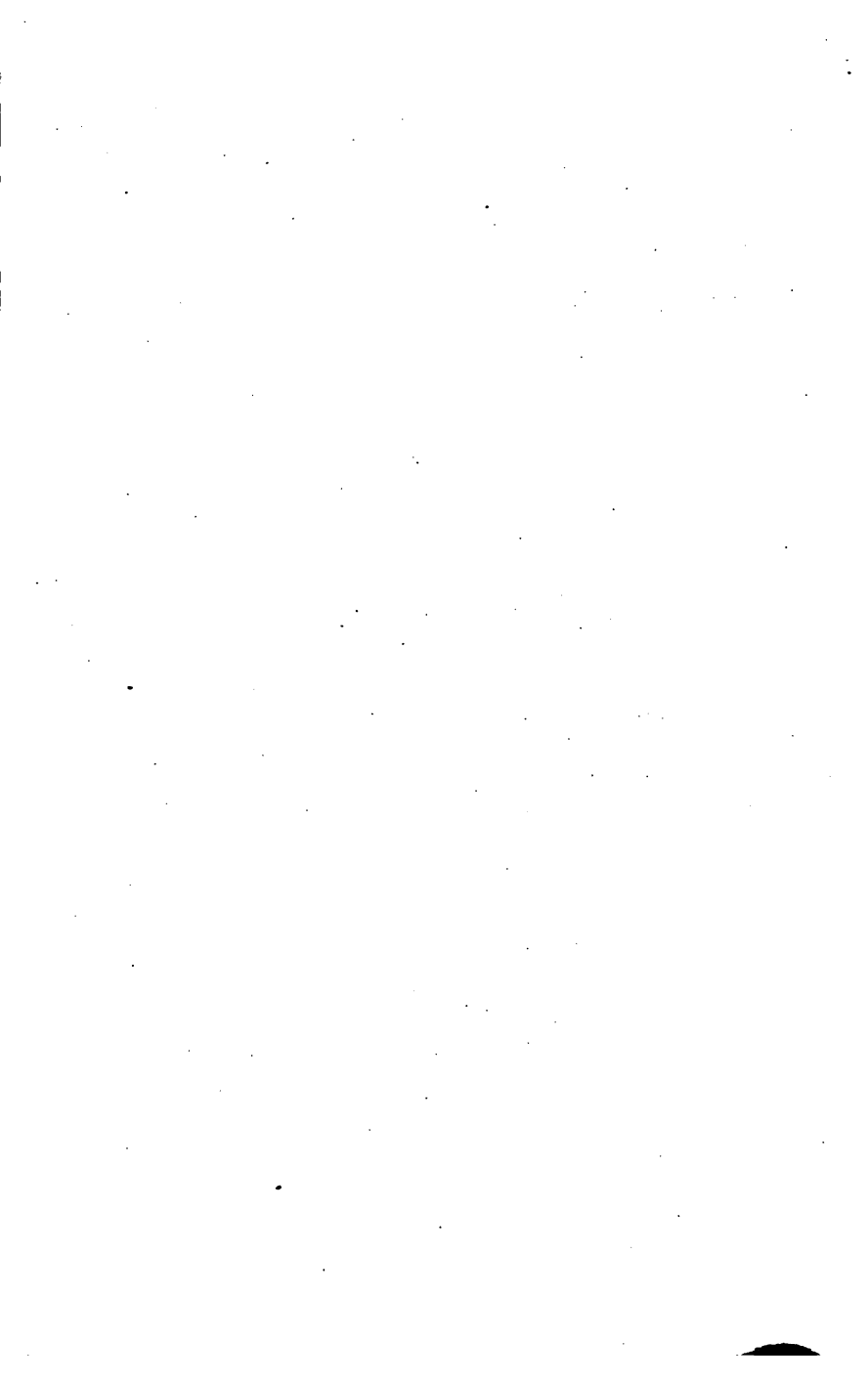and the meridian ? — What are on the VI. o'clock hour
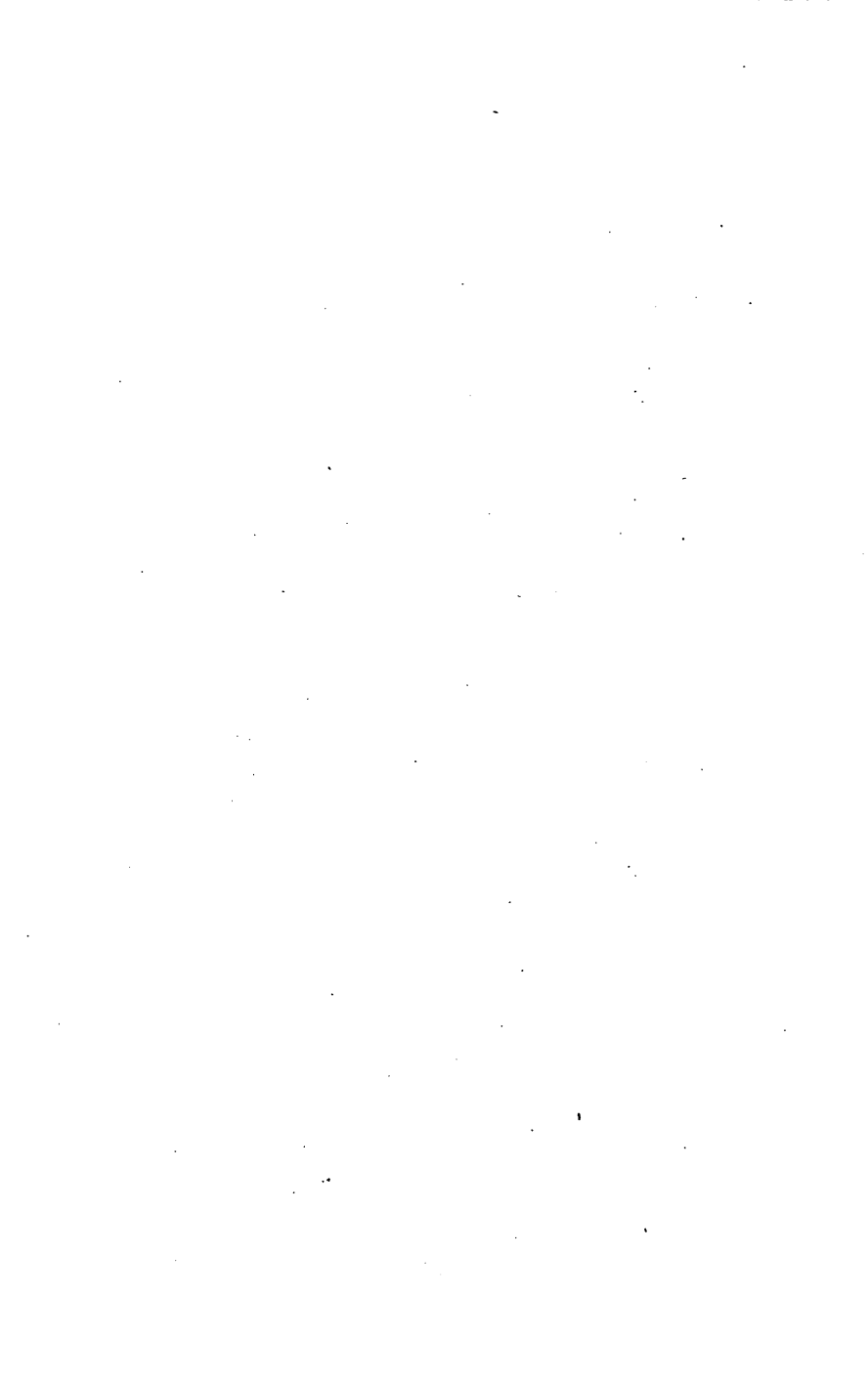circle, &c. ?